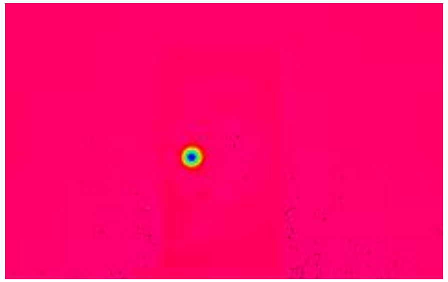
New electron Source, prototype, first results

- ❑ **AWAKE electron injectors**
- ❑ **ARTI prototype status**
- ❑ **Conclusion and outlook**

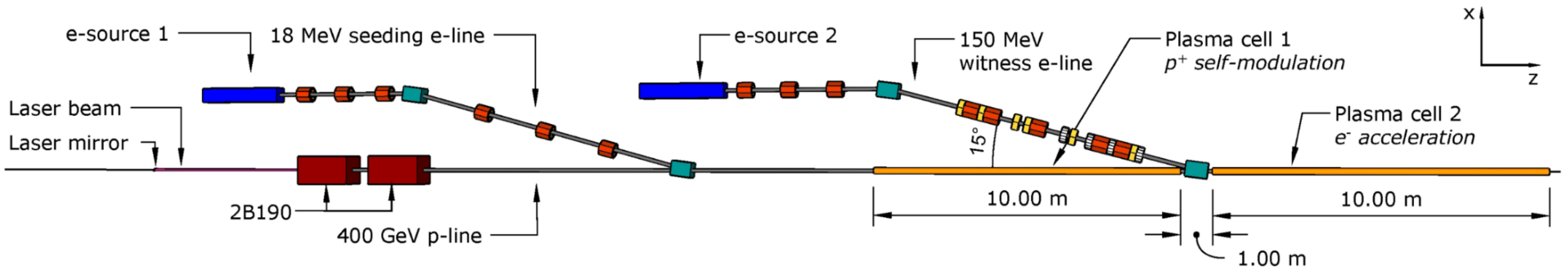


Awake Collaboration Meeting, March 11-13, Liverpool
Steffen Doebert

Parameters for both injectors

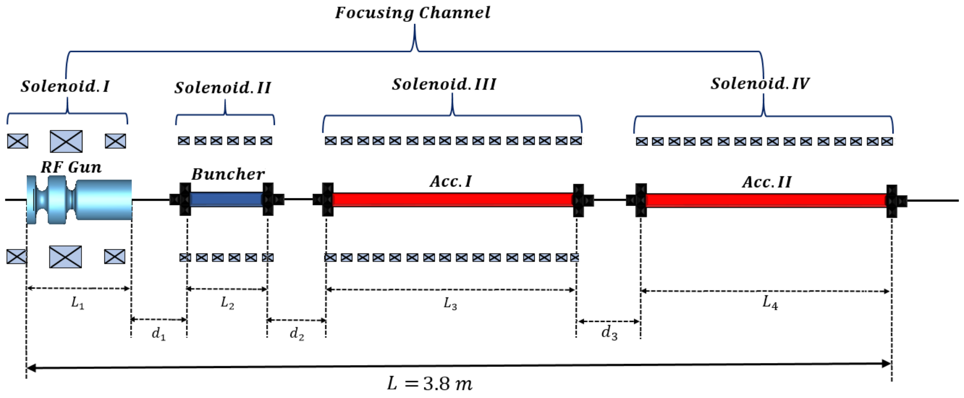
- Flexibility in the beam parameters which can be delivered keeping good energy spread and emittance
  Energy: +- 10%, Charge: up to 400 pC, Bunch length: 0.2-1 ps, beam size : see transport
- Constraint space for hardware
- Excellent timing stability and synchronisation with laser and self-modulation device

	18 MeV injector	150 MeV injector
Beam Energy (MeV)	18.5	150
Energy Spread ($\Delta E/E_0$) (%)	0.50%	0.20%
Energy stability ($\Delta E_0/E_0$)	1 x 10-2	1 x 10-3
RMS Bunch Length (ps)	≈2-3	≈0.2-0.3
Bunch Charge (pC)	100 -600 pC	100 pC
Emittance (mm mrad)	2 - 5	2
Beam size (µm)	~ 190	5.75

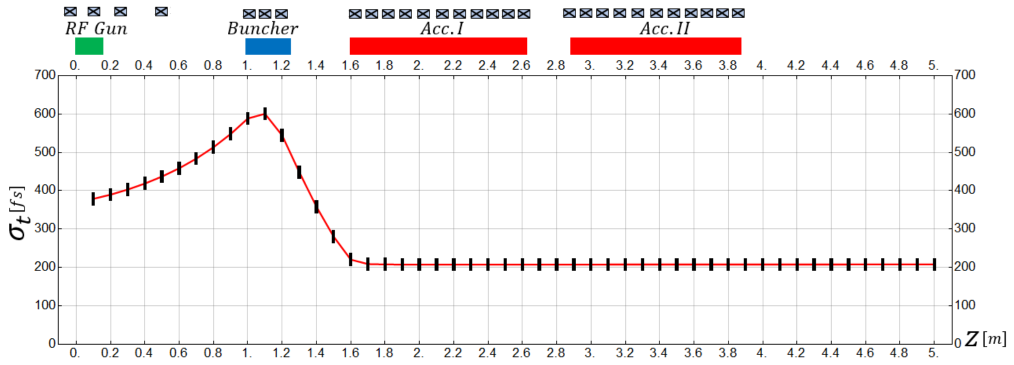


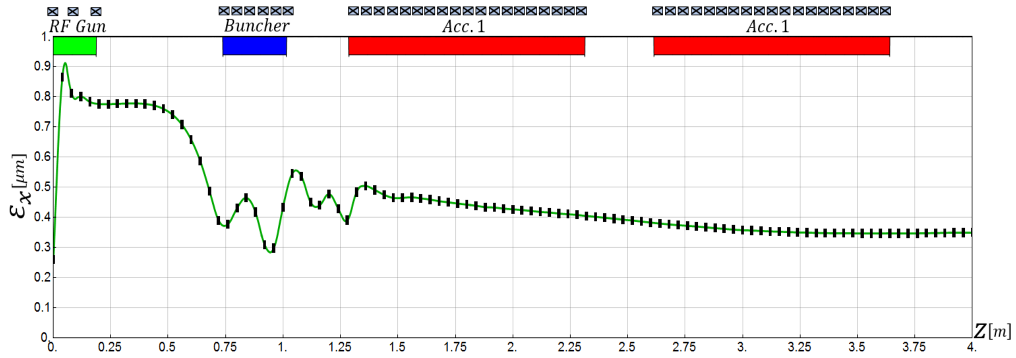
150 MeV injector – beam dynamics design

- Very compact electron injector
- Simulated parameters within specifications



$E_k[MeV]$	$\sigma_r[mm]$	$\sigma_t[fs]$	$\varepsilon_x[\mu m]$	$\sigma_E[\%]$	$I_{av}[A]$
150	0.14	**207**	0.44	**0.09**	168





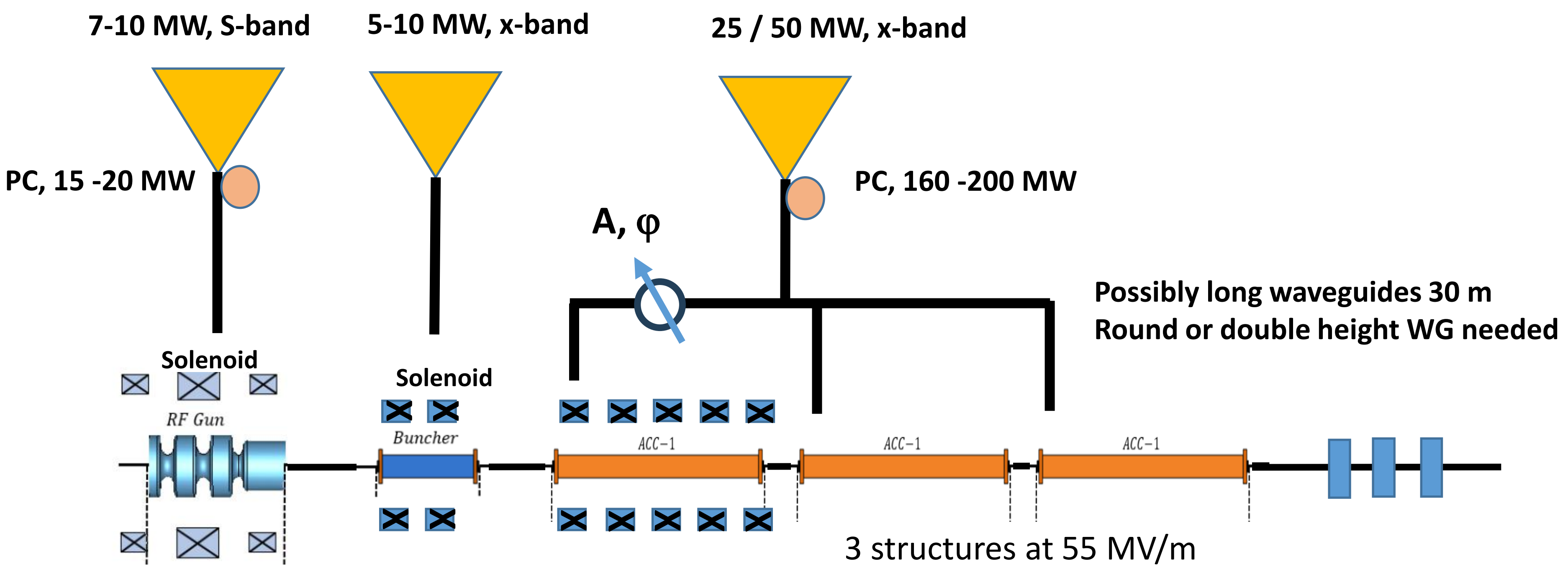
Laser parameters

$\lambda[nm]$	$w[ev]$	$r[mm]$	$t[ps]$	$q[nc]$
262	4.31	1.0	1.0 – 5.0	0.1-1.0

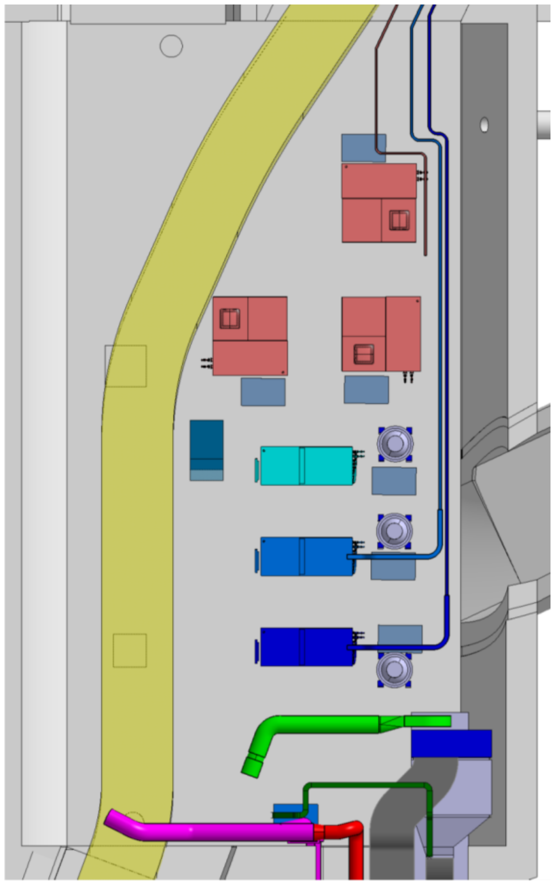
RF parameters

Parameter	RF Gun	Buncher	Acc. I	Acc. II
Frequency	3.0	12.0	12.0	12.0
Gradient	$120MV/m$	$35MV/m$	$80MV/m$	$80MV/m$
N. Cell	1.5	30	120	120

150 MeV injector – RF layout



Klystron layout on the tunnel



- Total Energy 100- 160 MeV, 10 Hz rep. rate, single bunch
- Will use CLIC developed x-band components as much as possible
- Multiple RF-power configurations studied

Studied alternative scenarios

Beam dynamics:

- 3 identical structures, one 50 MW klystron → Save small klystron, waveguide run and buncher structure

RF power variants:

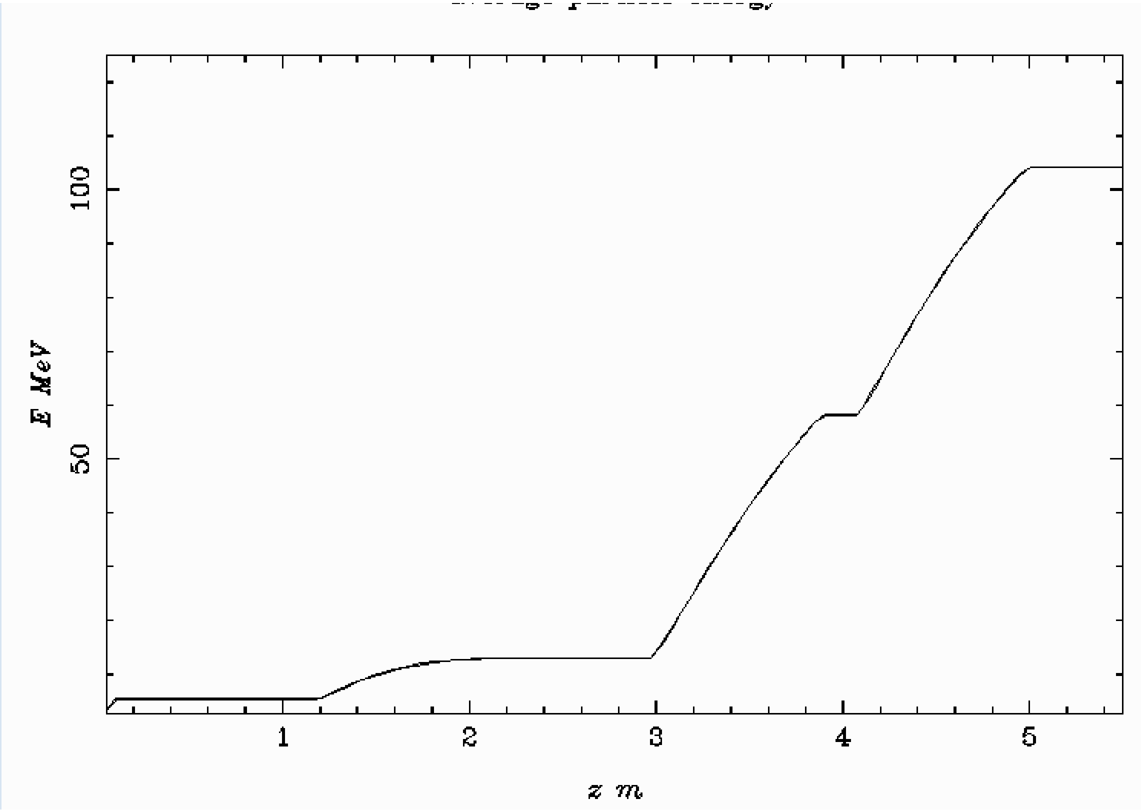
- One 25 MW klystron for acceleration, small 8 MW klystron for bunching → less expensive klystron and modulator
- Only one 25 MW klystron for everything → less expensive klystron, save second waveguide run and small klystron

Integration scenarios:

- Keep Run 1 modulator (PPT) for LINAC 1, instead of two K100 modulators → no new hardware needed
- Use K400 modulator instead of PPT → better performance and stability
- Replace K400 x-band with 2x K200 x-band → essentially staged scenario to upgrade energy later

AWAKE RUN 2 alternatives

3 identical structures, first one for bunching: 100 MeV with modest gradient,

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      S_Pos(1)=0.0,  S_smooth(1)=10,   MaxB(1)=0.28,
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S_smooth(2)=10,   MaxB(2)=0.25,

/

&Cavity
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      Phi(1)=30.0,

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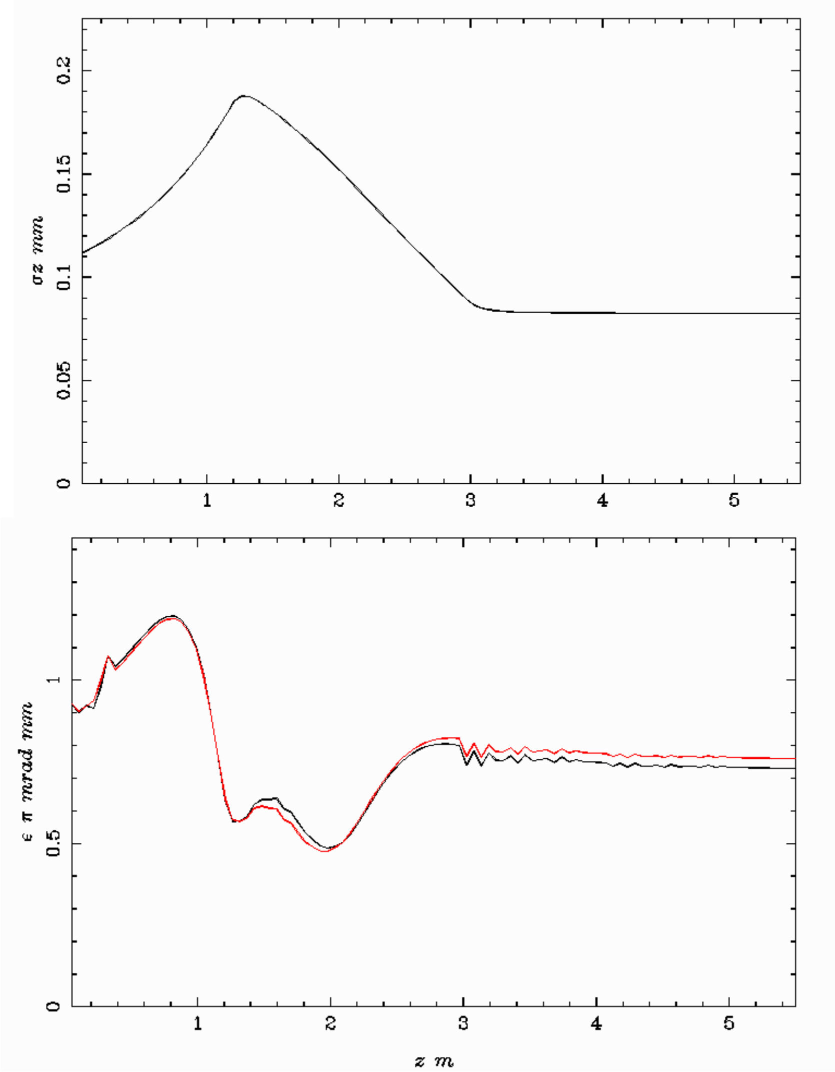
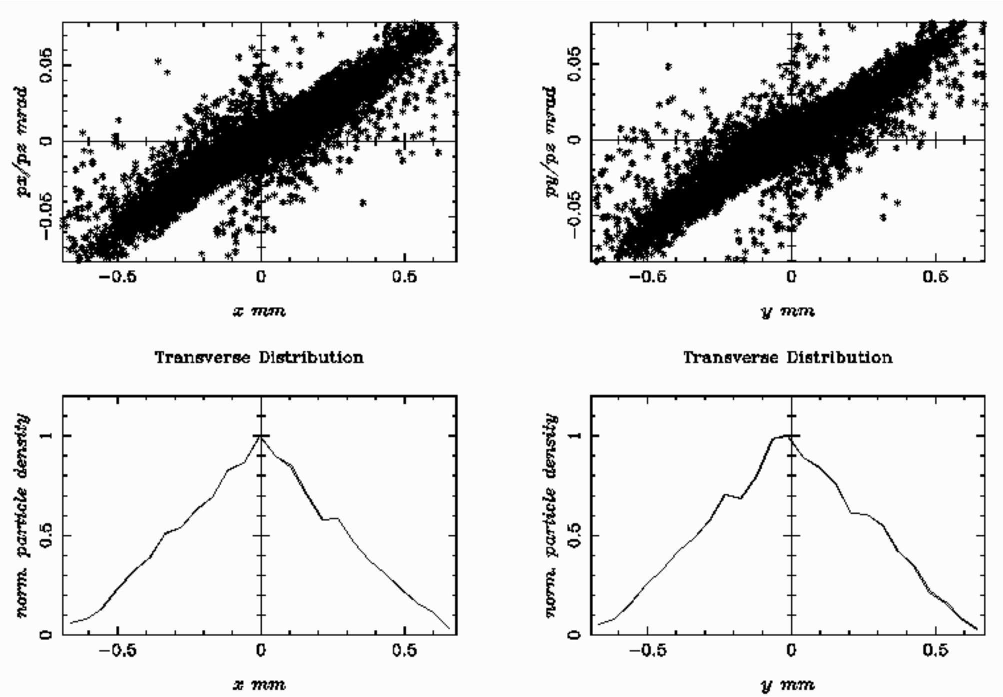
AWAKE RUN 2 alternatives

3 identical structures, first one for bunching: 100 MeV with modest gradient, energy spread 150 keV, bunch length 83 um, emittance 0.75 um



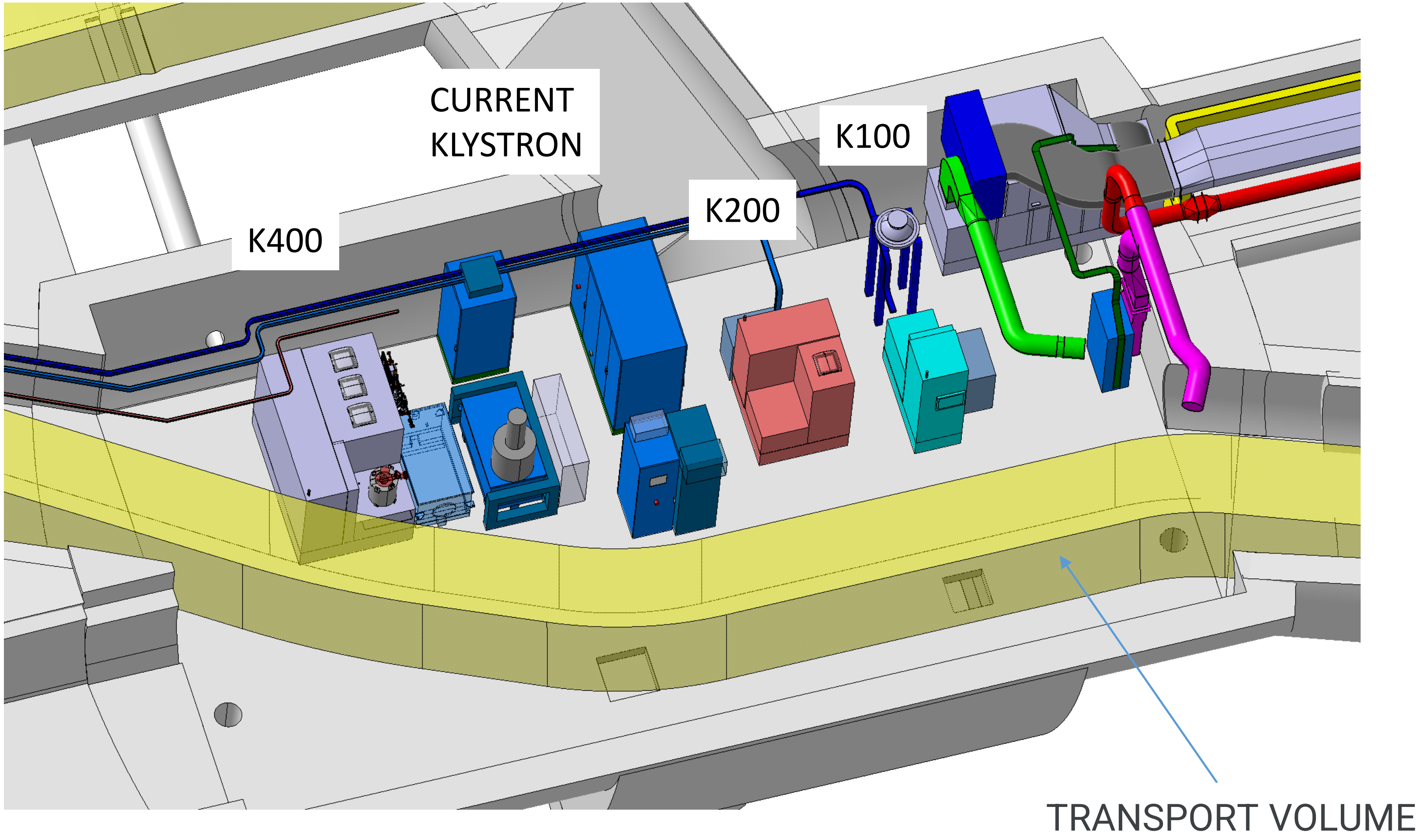


AWAKE RUN 2 alternatives performance summary

- 50 MW klystron: 3*54 MV/m =7.5 MW out of klystron per structure; 35% waveguide losses; bunching separate → > 150 MeV baseline scenario
- 50 MW klystron: 1 * bunching (2MW) +2*54 MV/m; → ~ 100 MeV
- 25 MW klystron: 3* 43 MV/m; → ~ 116 MeV with separate bunching
- 25 MW klystron: 1 * bunching (2MW) + 2* 47 MV/m; → ~ 93 MeV with separate bunching
- The possibility to run at higher charge gets compromised with those scenarios, simulations indicate 200 pC might still be OK but 400 pC has already higher emittance

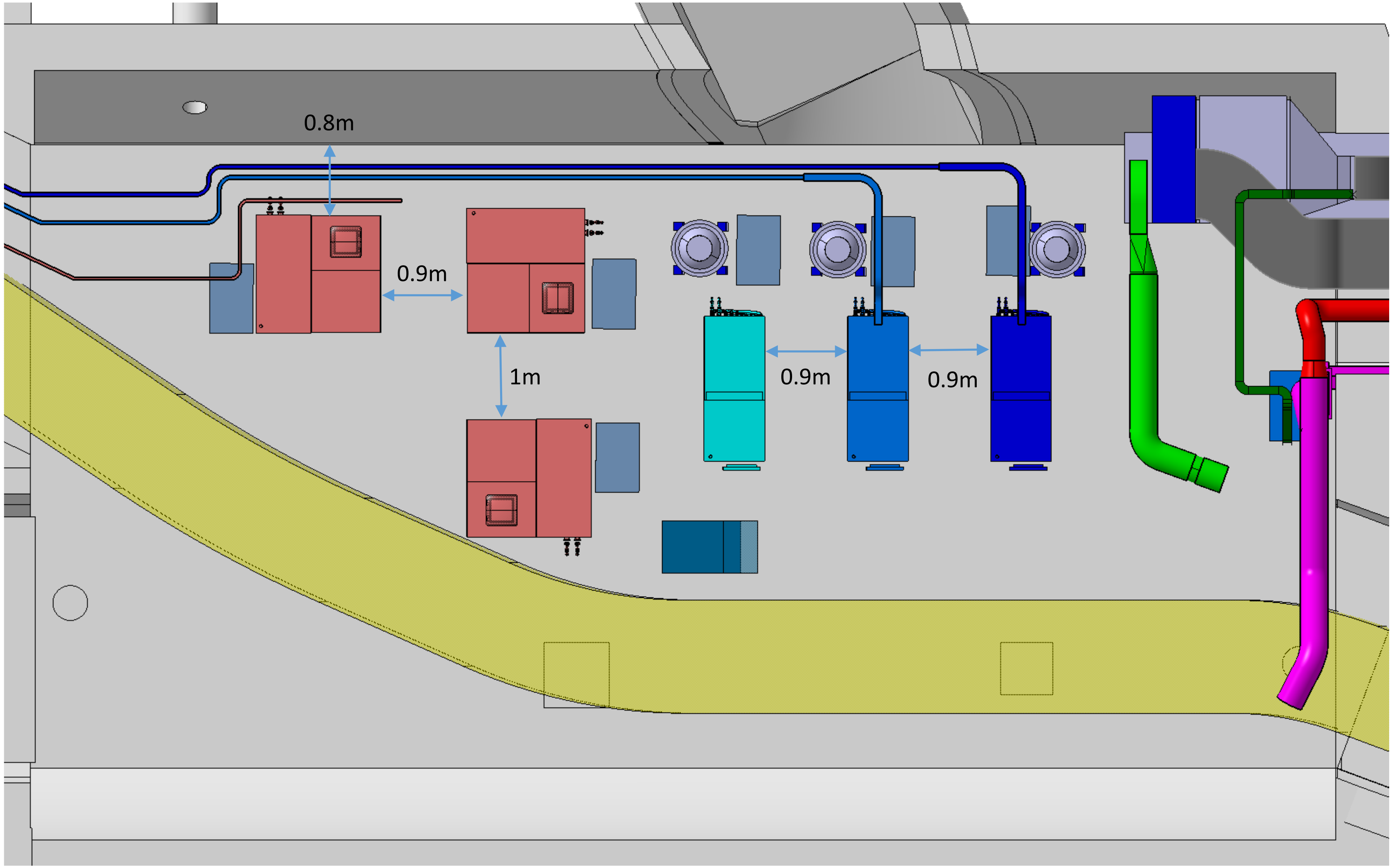
SOLUTION 1

Keep PPT modulator from Run1 for Linac 1



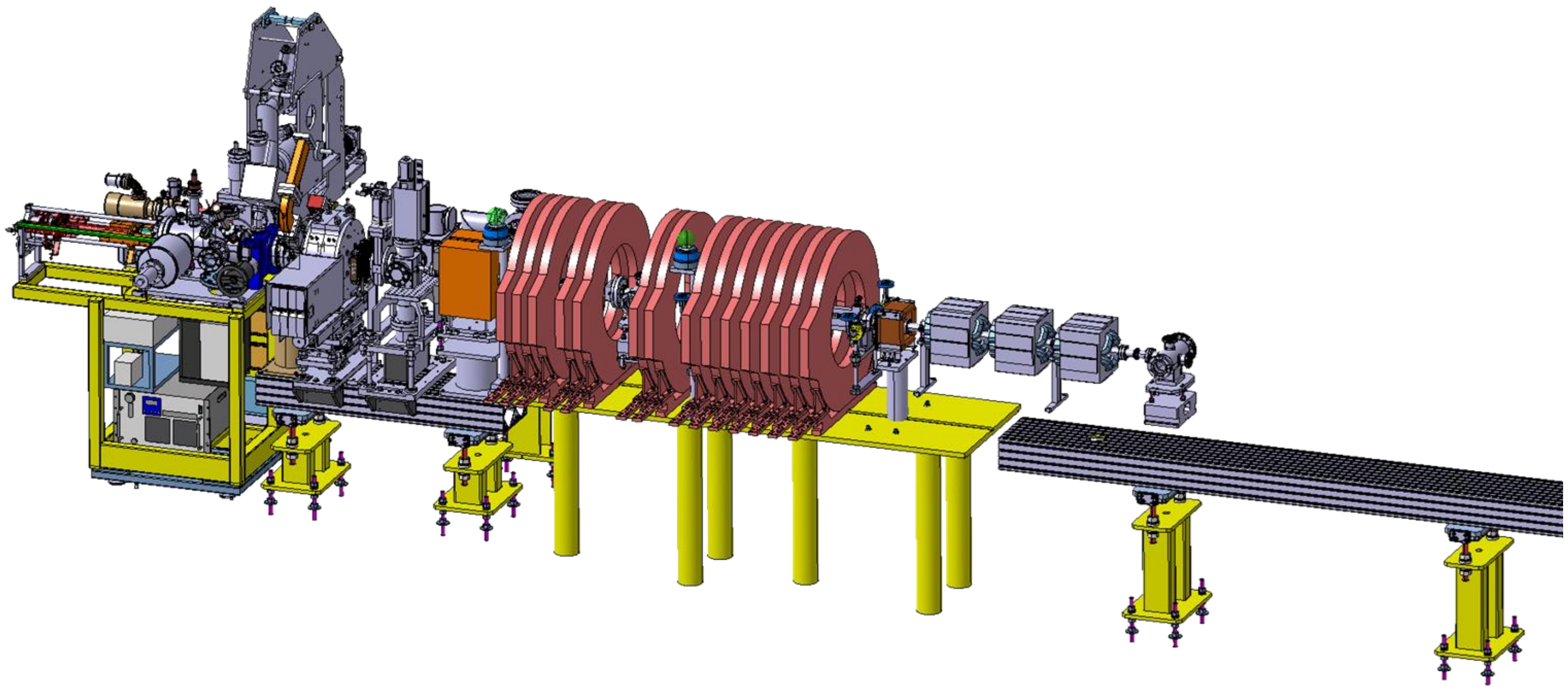
SOLUTION 2-B

Using three 25 MW x-band klystrons



150 MeV injector – Prototype

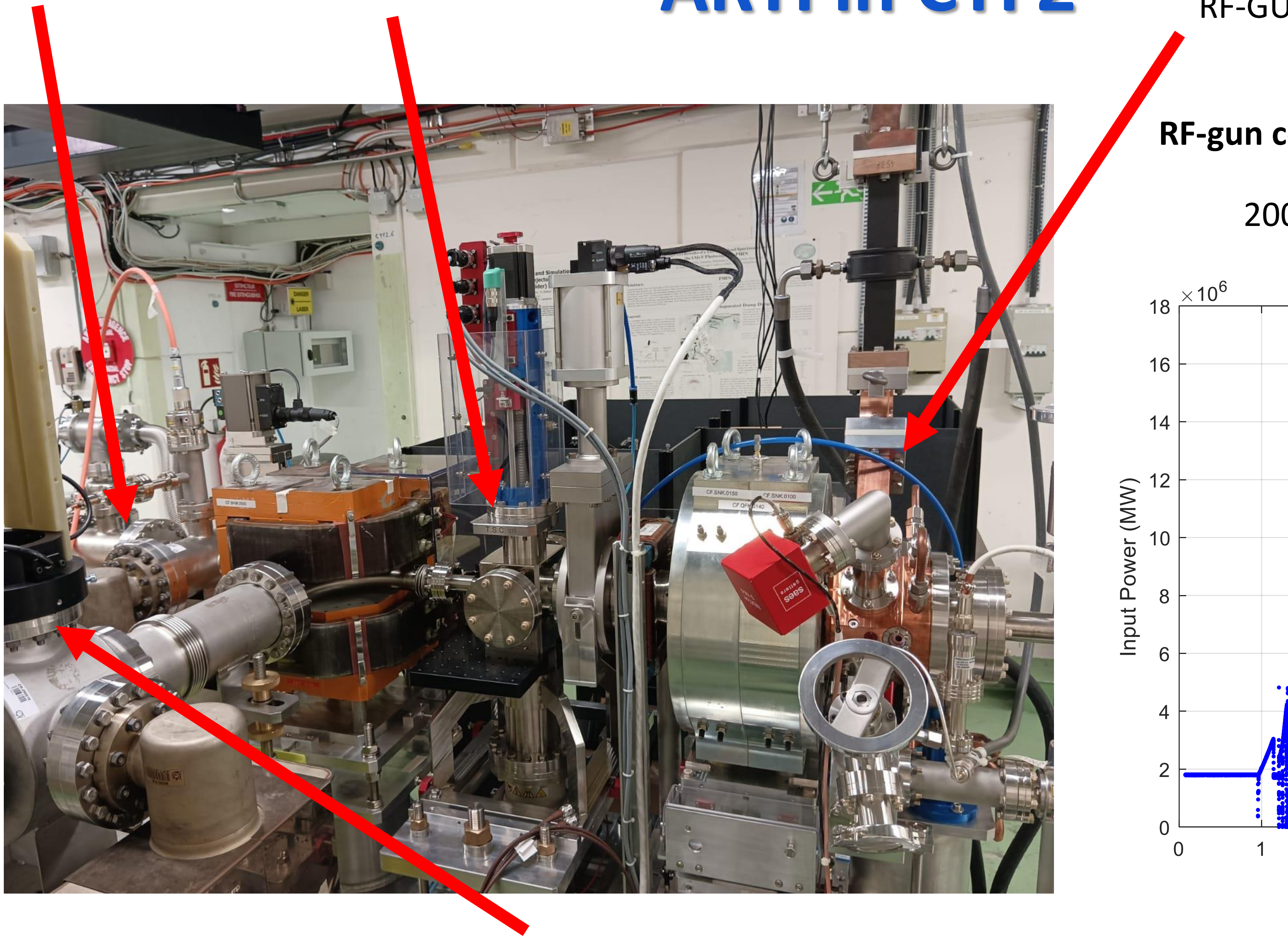
- **ARTI (AWAKE Run2 Test Injector)**
- Reduced scale prototype, 60 MeV, INFN gun, CLIC-structure as buncher and PSI-linearizing structure for acceleration.
- Goal: demonstrate the velocity bunching and emittance preservation with x-band
  Prototyping of key accelerator hardware and diagnostics
- Gaining experience before installation in the AWAKE tunnel



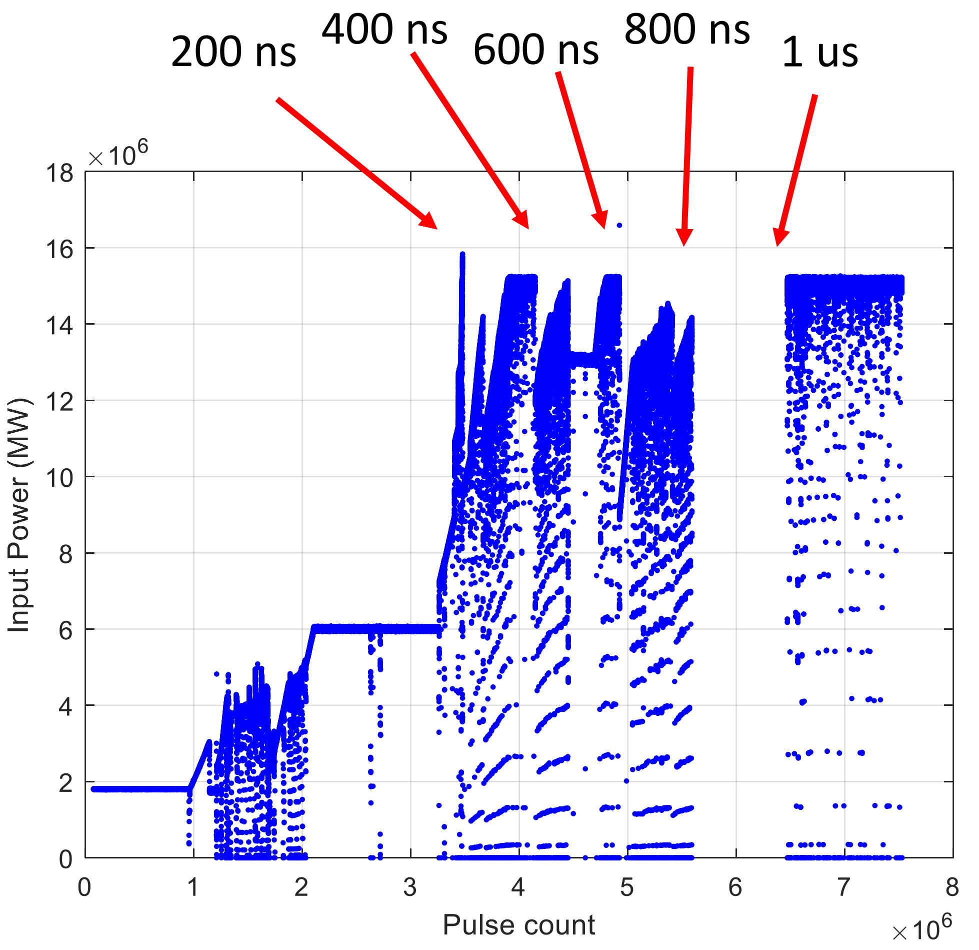
ARTI status

- RF-gun and diagnostics operational
- Magnets for second phase installed
- Vacuum system will be next
- Missing the x-band waveguide system and the klystron (still at CPI for repair)
- First ‘user’ experiment planned in spring: Vlad’s CBS experiment

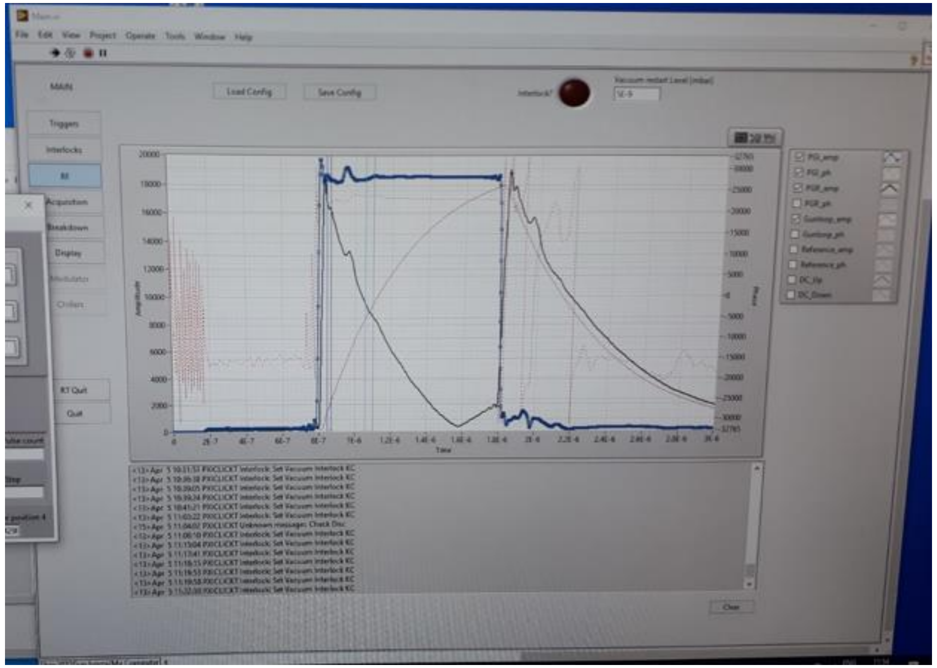
ARTI in CTF2

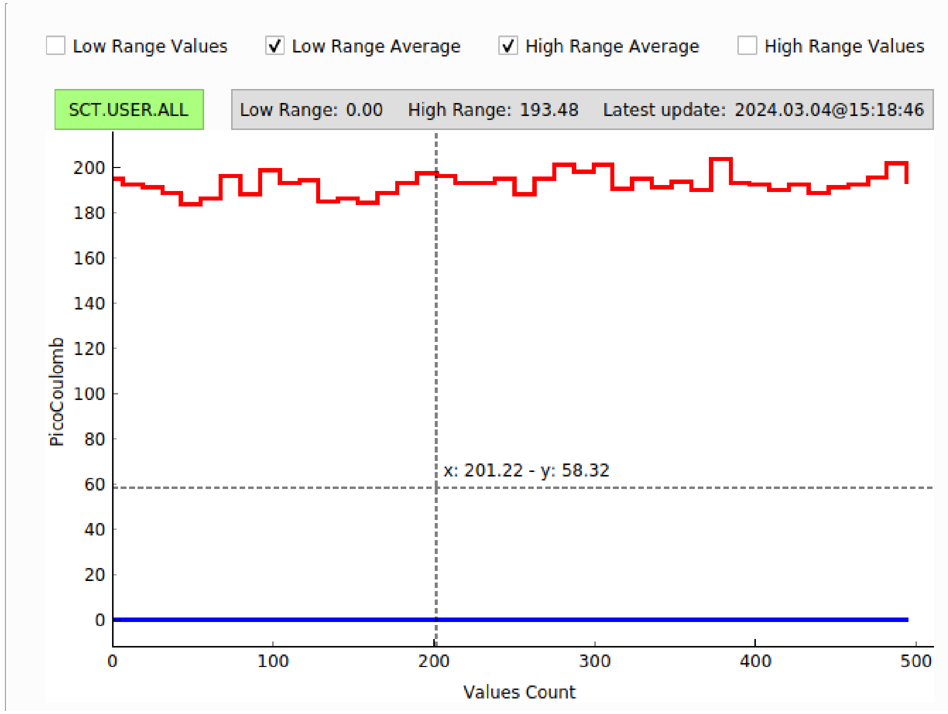


RF-gun conditioned to 120 MV/m on the cathode



First results with beam



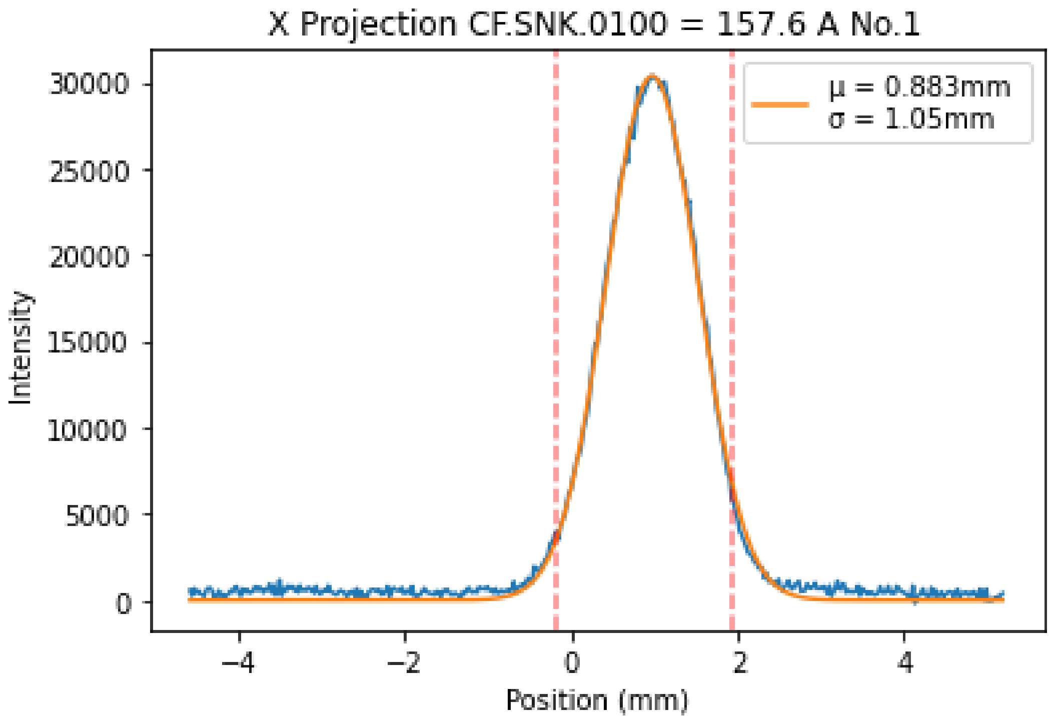


RF set-up:
Input Power: 13 MW
Gradient: 114 MV/m

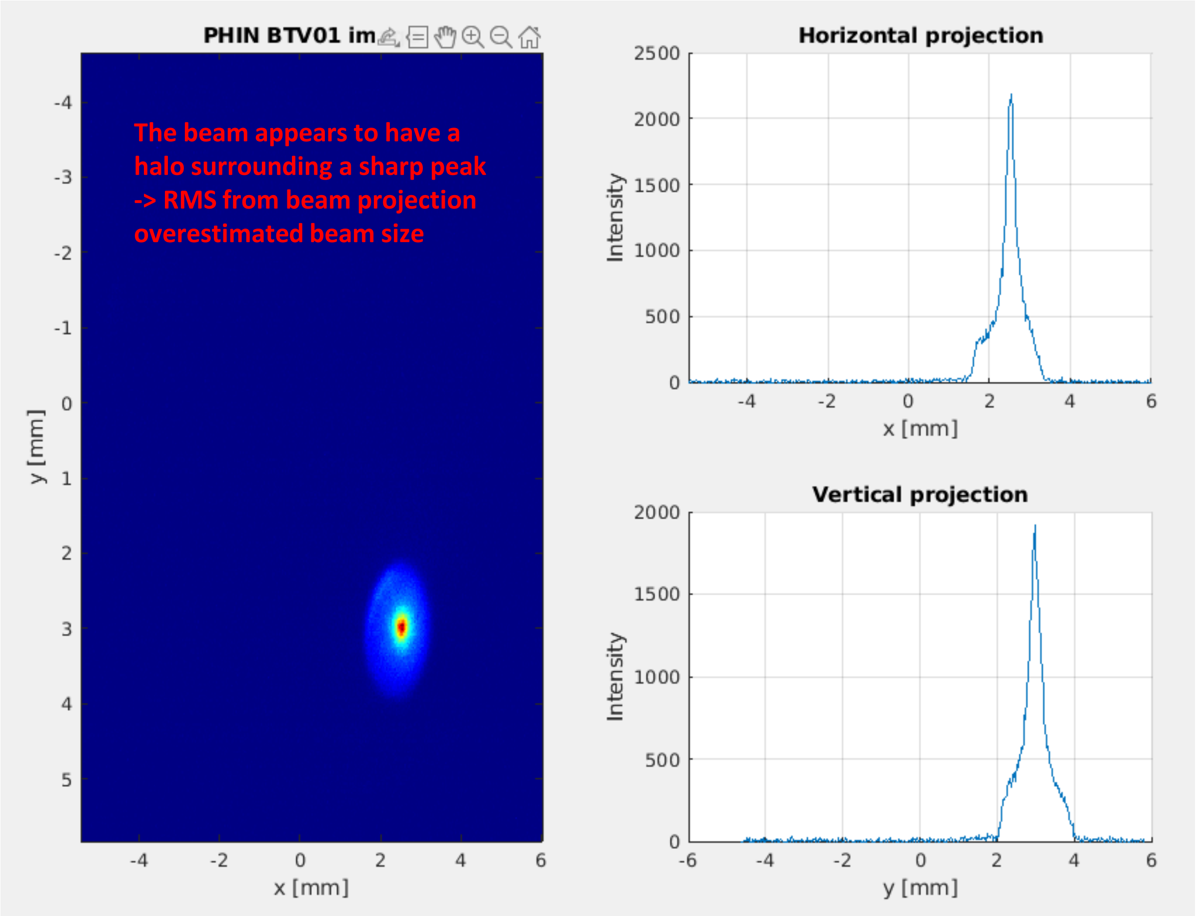
Beam charge:
Faraday Cup: up to 400 pC with short laser pulse
Copper Qe: 9 x 10^{-4}
Very promising for Copper cathodes
No dark current basically not measurable for time being:
< 5 pC (preliminary)

Beam profile characterisation

Typical beam profile



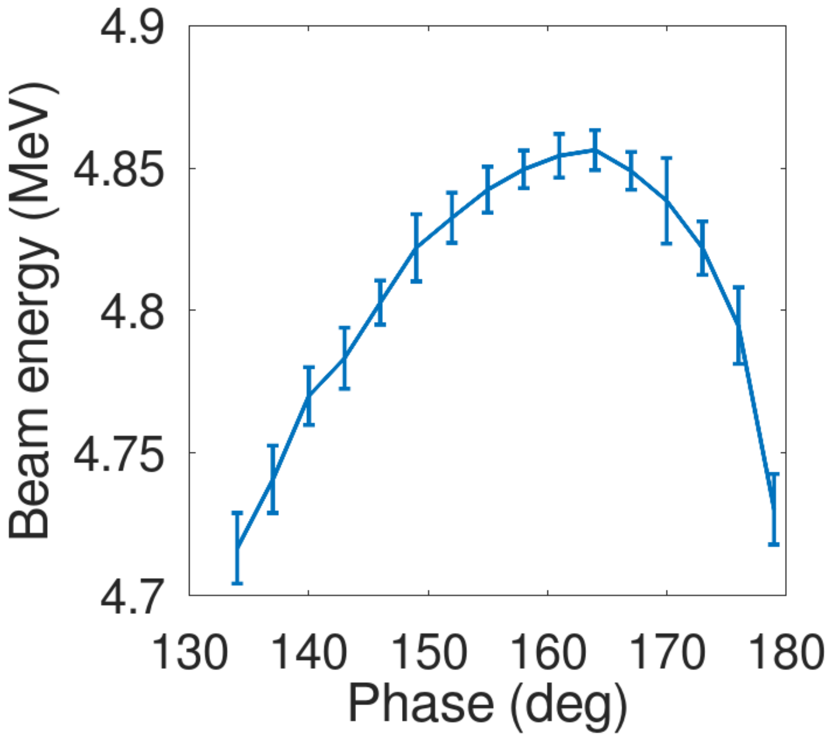
Screenshot of focused beam

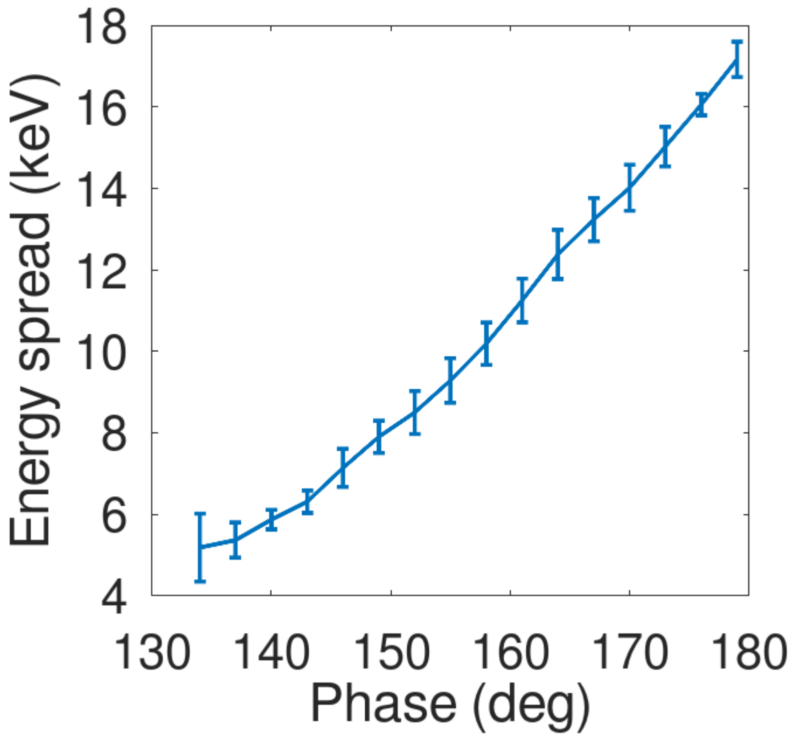


Vlad Muscat, Anton Eager

Phase scans

- The on-crest phase was shifted by 20 deg. On-crest now at 163 deg.





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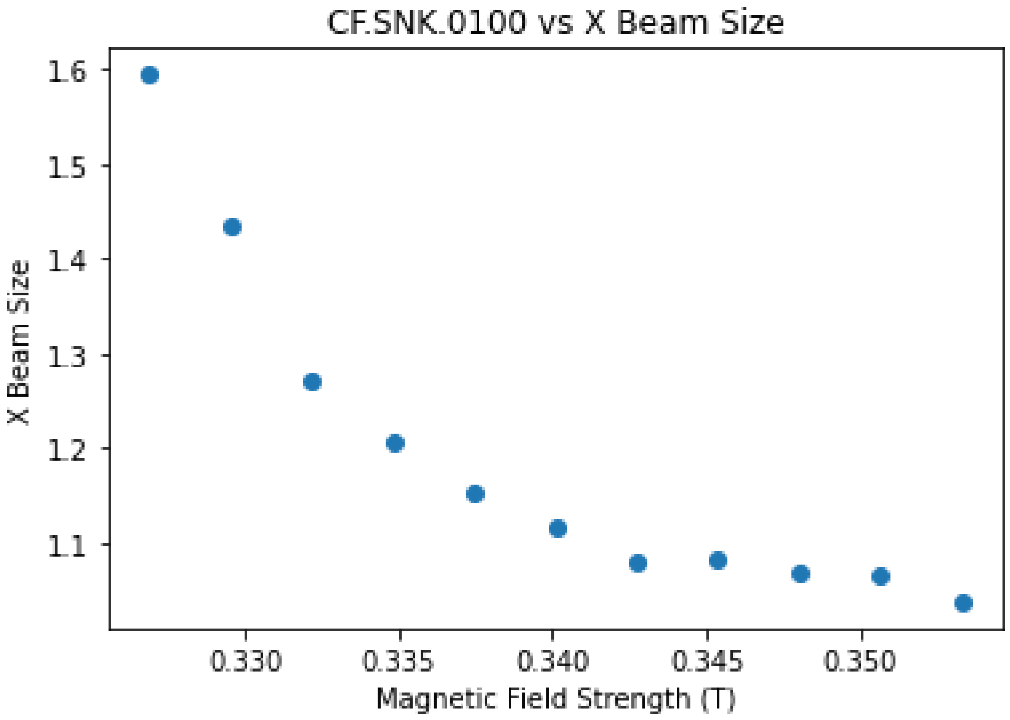
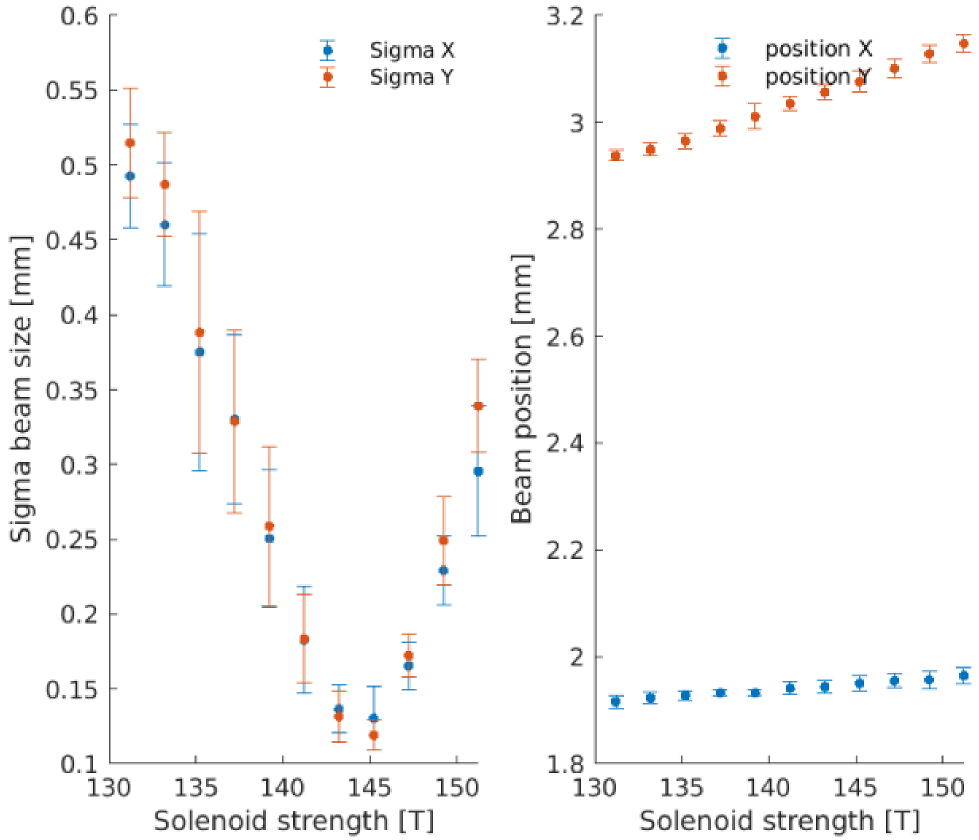
Solenoid scans



Laser pulse length = 112.7 fs RMS



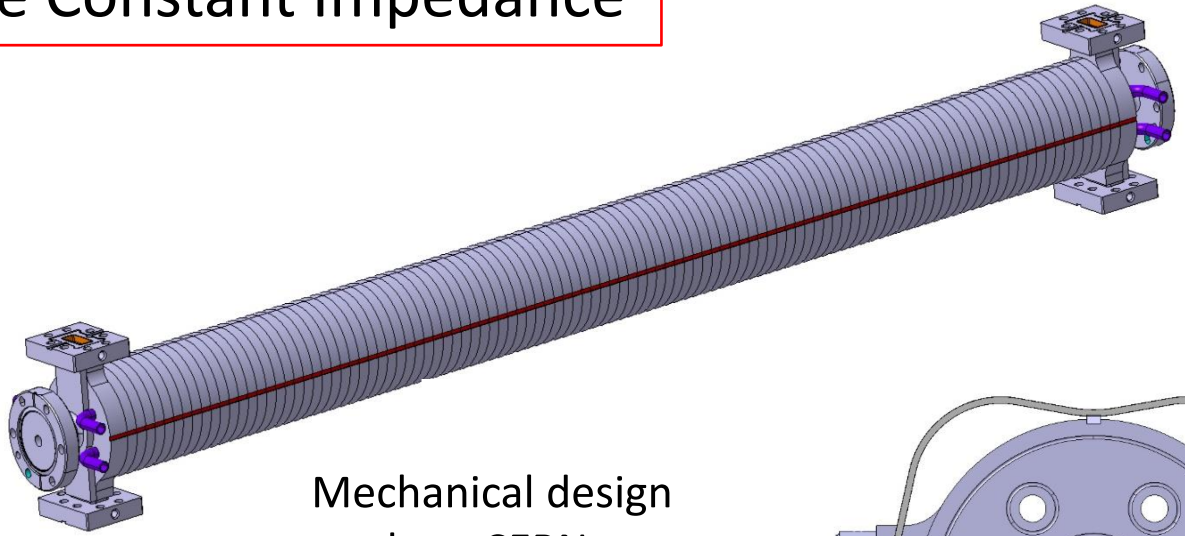
Laser pulse length = 327 fs RMS

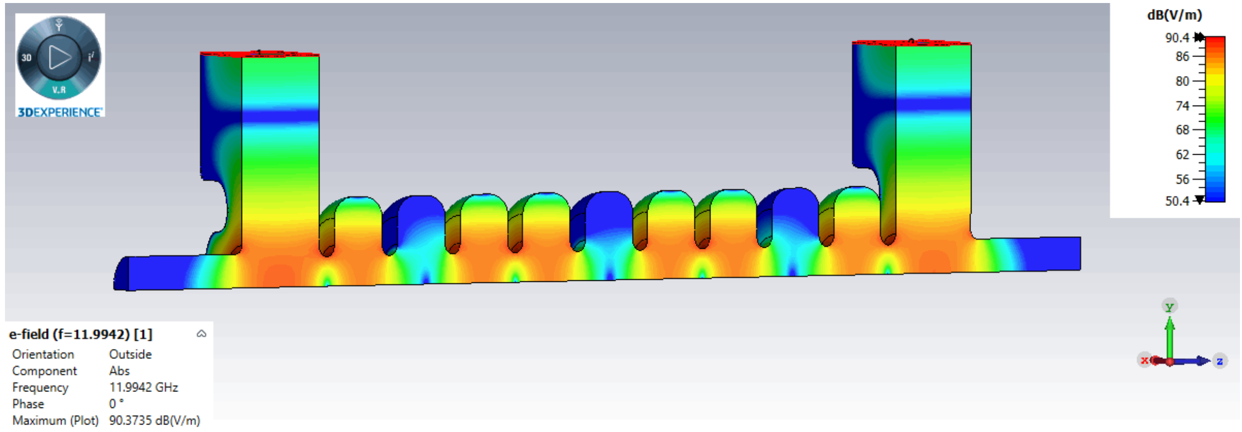
Vlad Muscat, Anton Eager

X-band structure developments

Travelling wave Constant Impedance

Shunt Impedance [MΩ/m]	100
Group Velocity vg/c [%]	2.4
Q-Factor	7061
Attenuation [1/m]	0.7
Length [m]	0.9

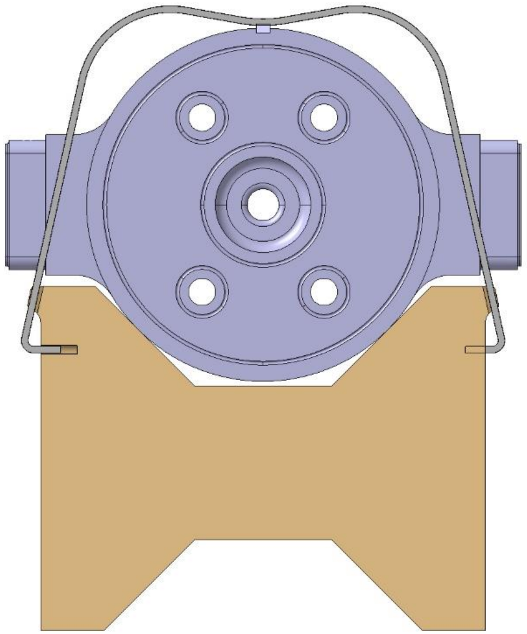




Mechanical design made at CERN

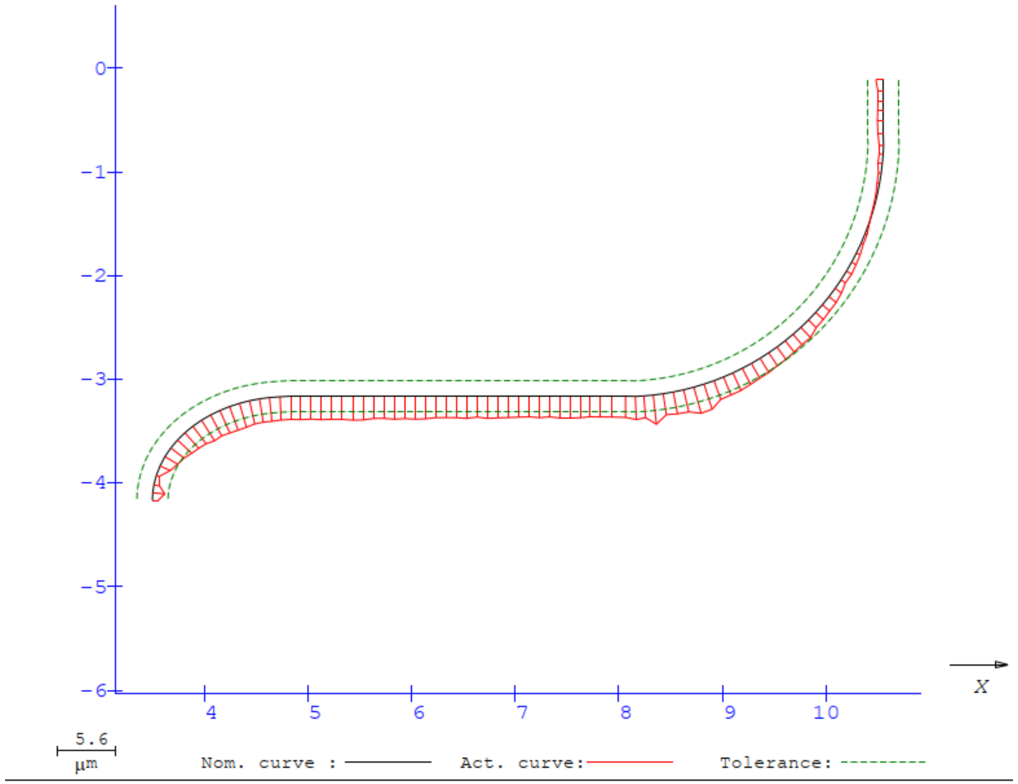
CLIC style tolerances
Vacuum brazing design

Structure to be inserted in a solenoid of 150 mm diameter bore radius



Designed by INFN Frascati, D. Alesini, M. Diomede,
for CompactLight and EuPraxia

First short prototype under construction

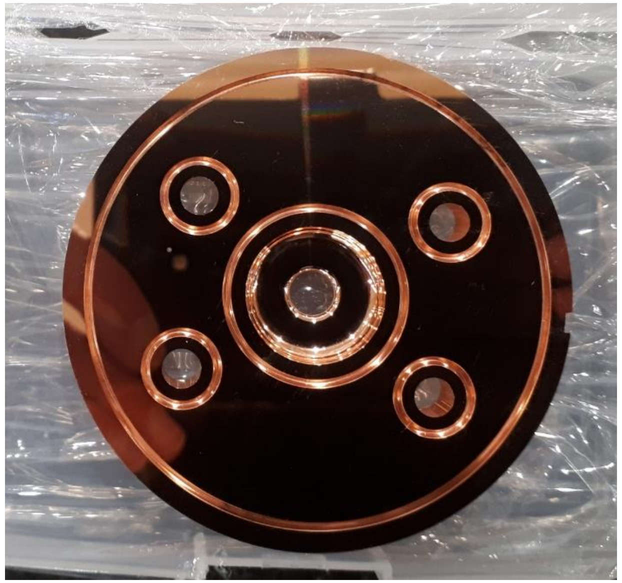


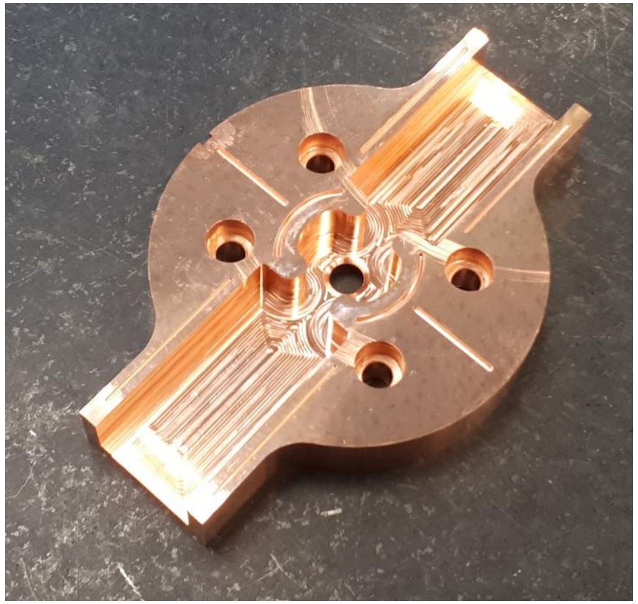
Notation : Disc
Ser. No. : 11
Element : E2_SECT_COMP(1)

Producer : SCIBOR Karol
Part No. :

Draw. No. : SPSACTXA0003
Department:

			X	Y	Z	Nr.
Form ....: 0.004	Min. Deviat.:	-0.003	8.332	0.000	-3.151	43
Lower Toler. :-0.002	Max. Deviat.:	0.001	10.555	0.000	-0.111	1
Upper Toler. : 0.002	Profile X+					
Error Magnif.: 100						
No. of points: 97						





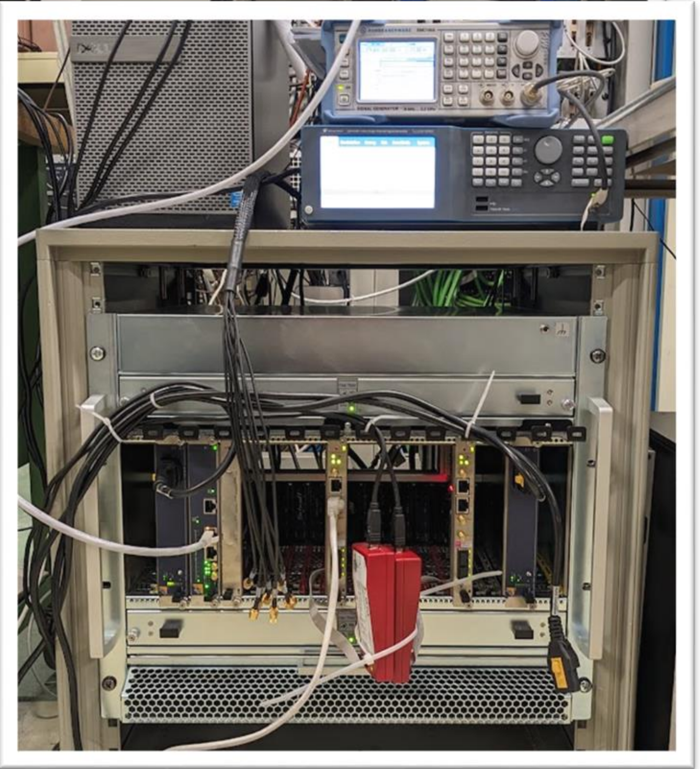
Conclusion and outlook

- Further optimisation of the existing baseline injector for Run 2c with respect to performance, cost and integration
- Very good start of the beam commissioning. No major problems spotted so far
  Of course, fine tuning is needed and systematic measurements.
  Clearly much more work to do !
- Will alternate commissioning periods with installations periods to complete the injector
- Interesting times ahead, a first visible piece of hardware for Run 2c and a first ‘user’ experiment on CBS at low energy.
- Thanks to Jordan Arnesano for his contributions to AWAKE
  Welcome to Anton Eager to take over in December

Additional material

μ–TCA development for LLRF with Uppsala

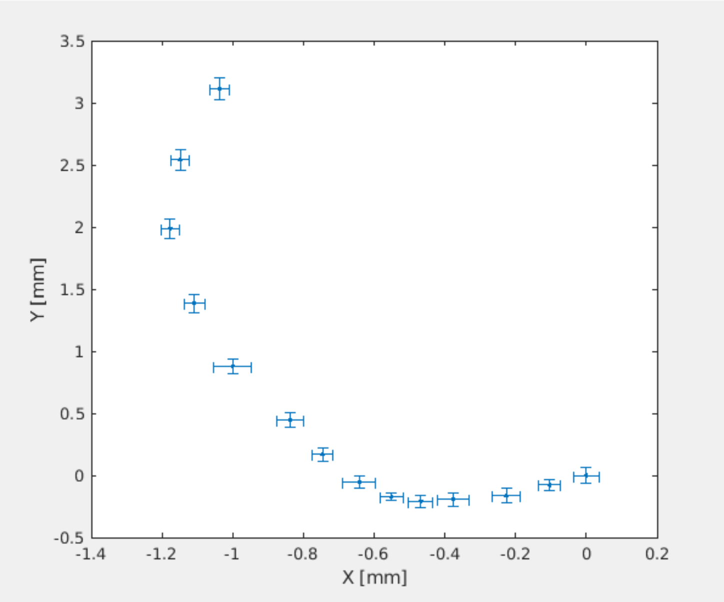
- **System shipped to CERN from Uppsala, installed in the form CLIC test facility.**
- **RF signal acquisition, generation and feedback/forward loops tested.**
- **Use of DESY BSP and python GUI.**
- **External trigger injection through RJ45 connector on SIS8300KU AMC, distributed to mLVDS lines.**
    - Currently under test/development (still some bugs to iron out)
- **Work progressing well on a DESYRDL to CERN/Cheby convertor script.**



Modulator and S-band 40MW klystron (above)

MicroTCA crate and LO, CLK generators (right)

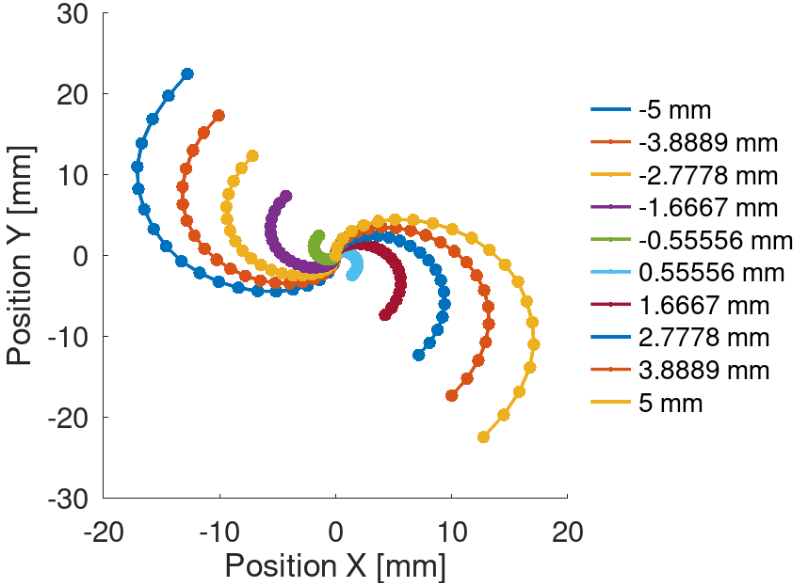
Centering the gun solenoid



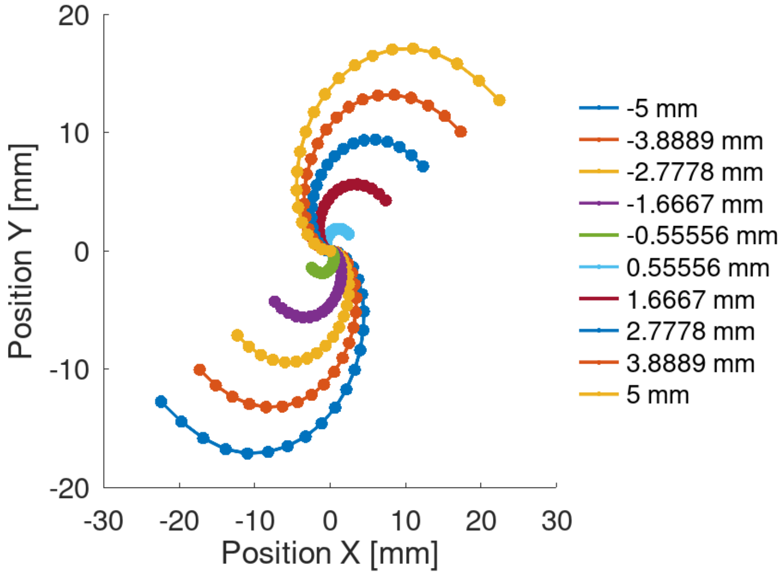
To further reduce the emittance from the gun, the position of the electron beam can be tracked through a solenoid scan

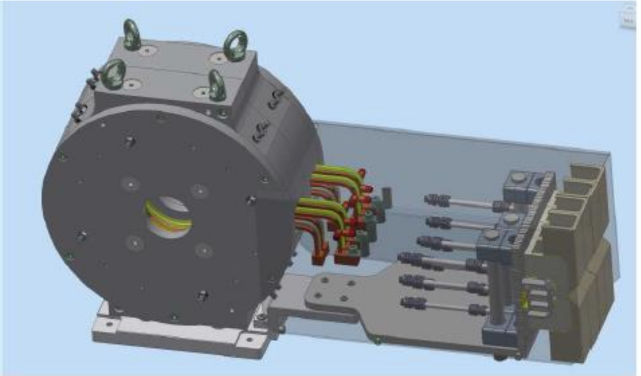
→ solenoid position and angle offset can be inferred by fitting the beam trajectory to simulations. Preliminary results predict a transverse misalignment less than 1 mm.

[Solenoid X offset]()

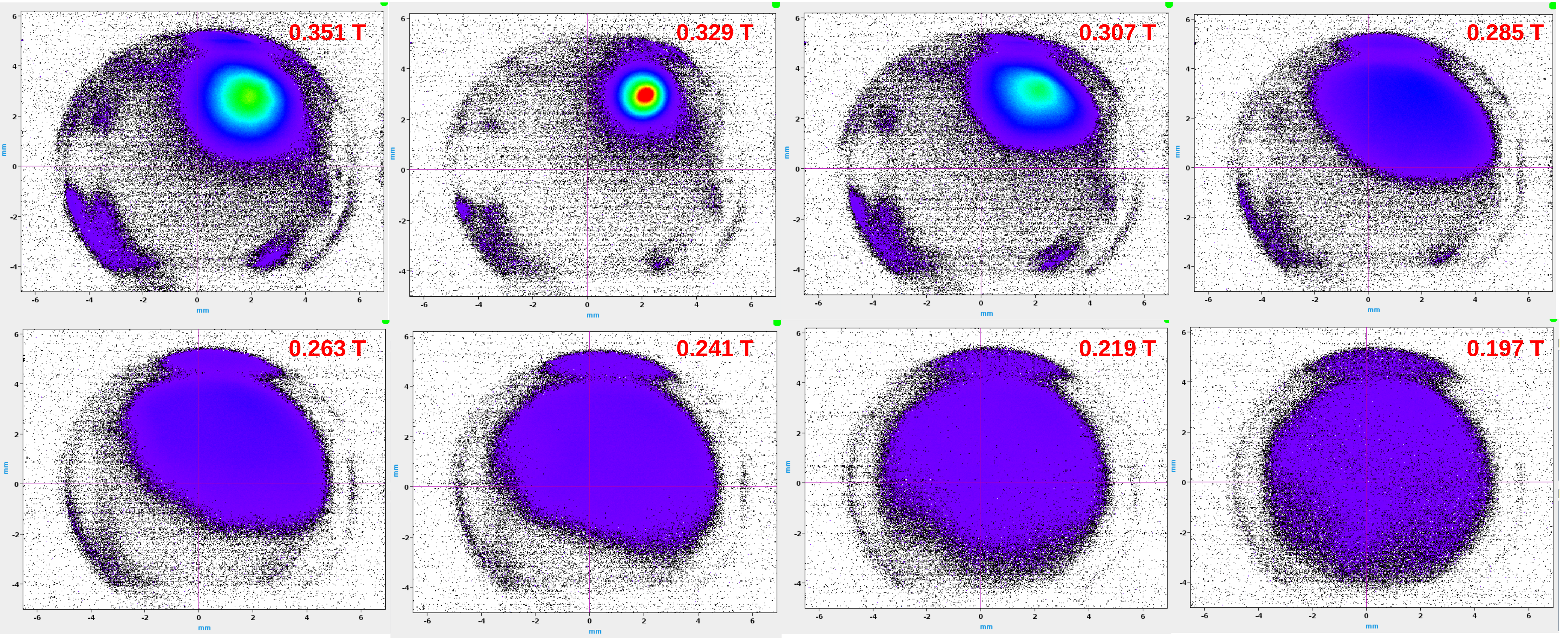


[Solenoid Y offset]()

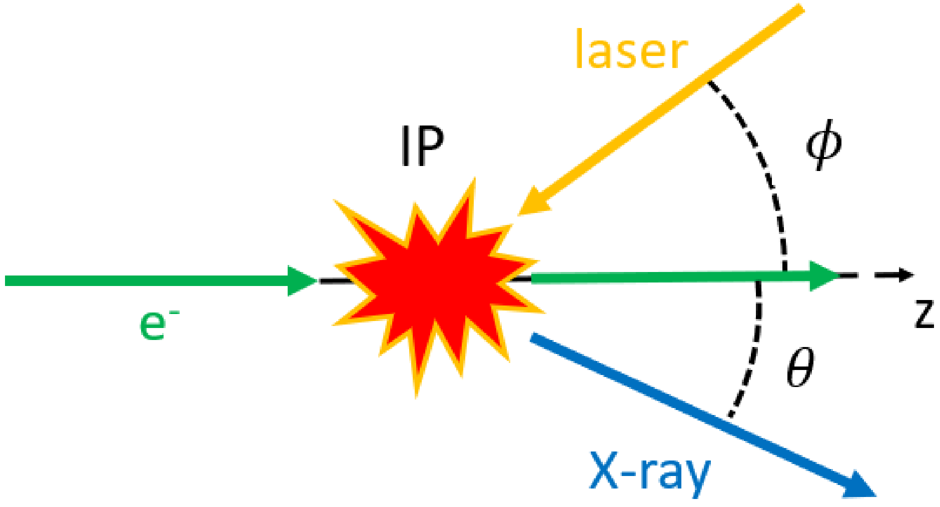




Stable beam point found



Compton backscattering



= The scattering of a low energy photon from an EM field to a high-energy photon (X-ray or gamma ray) during the interaction with a charged particle.

$$N_\gamma = \sigma_c \frac{N_e N_{\text{laser}} \cos(\phi/2)}{2\pi\sigma_{\gamma,y}\sqrt{\sigma^2_{\gamma,x}\cos^2(\phi/2) + \sigma^2_{\gamma,z}\sin^2(\phi/2)}}$$

Total flux

$$\mathcal{B} = \frac{\mathcal{F}}{4\pi^2\sigma_{\gamma,x}\sqrt{\epsilon_x/\beta_x}\sigma_{\gamma,y}\sqrt{\epsilon_y/\beta_y}}$$

Average brilliance

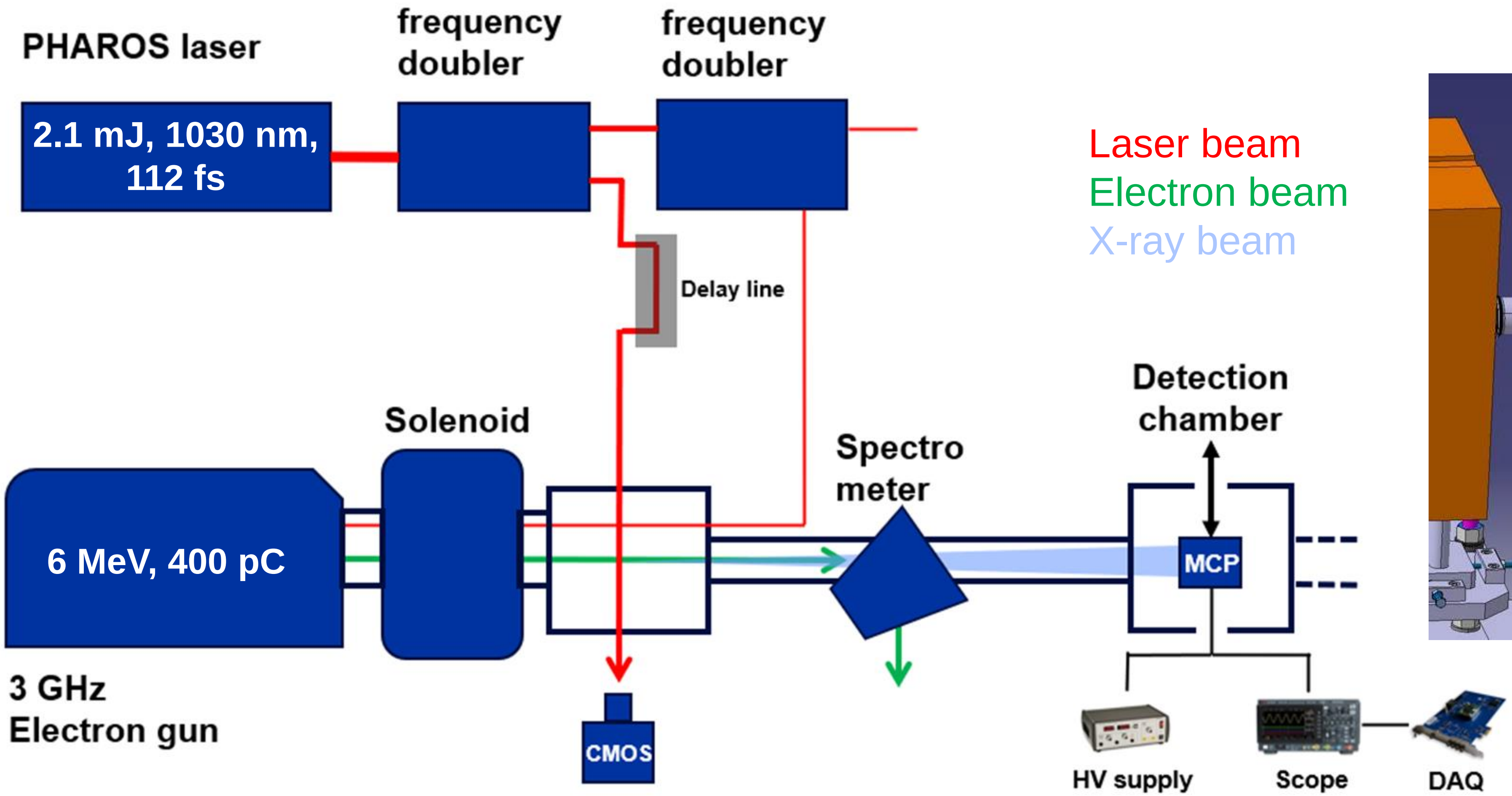
$$\frac{\sigma_{E_\gamma}}{E_\gamma} = \sqrt{\left(\frac{\sigma_{E_\theta}}{E_\theta}\right)^2 + \left(2\frac{\sigma_{E_e}}{E_e}\right)^2 + \left(\frac{\sigma_{E_{\text{laser}}}}{E_{\text{laser}}}\right)^2 + \left(\frac{\sigma_{E_\epsilon}}{E_\epsilon}\right)^2}$$

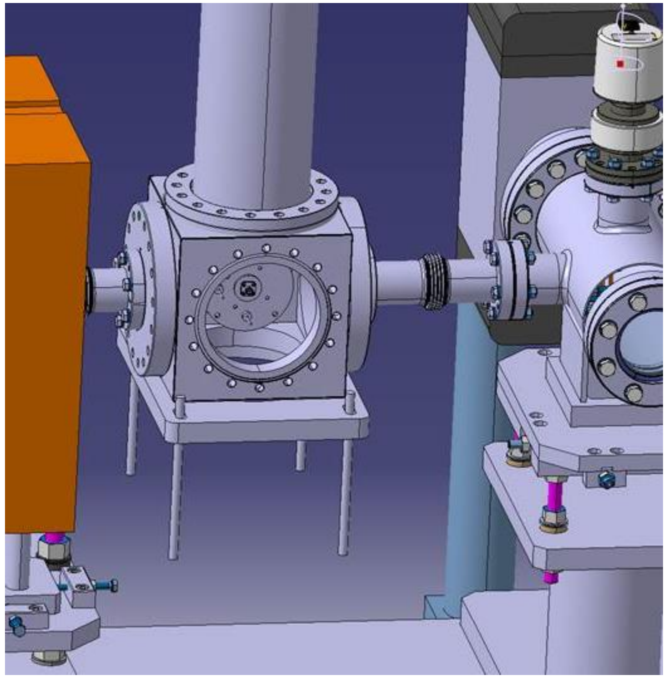
Photon bandwidth

$$E_{\text{X-ray}} = 2\gamma^2 E_{\text{laser}} \frac{1+\cos\phi}{1+\gamma^2\theta^2}$$

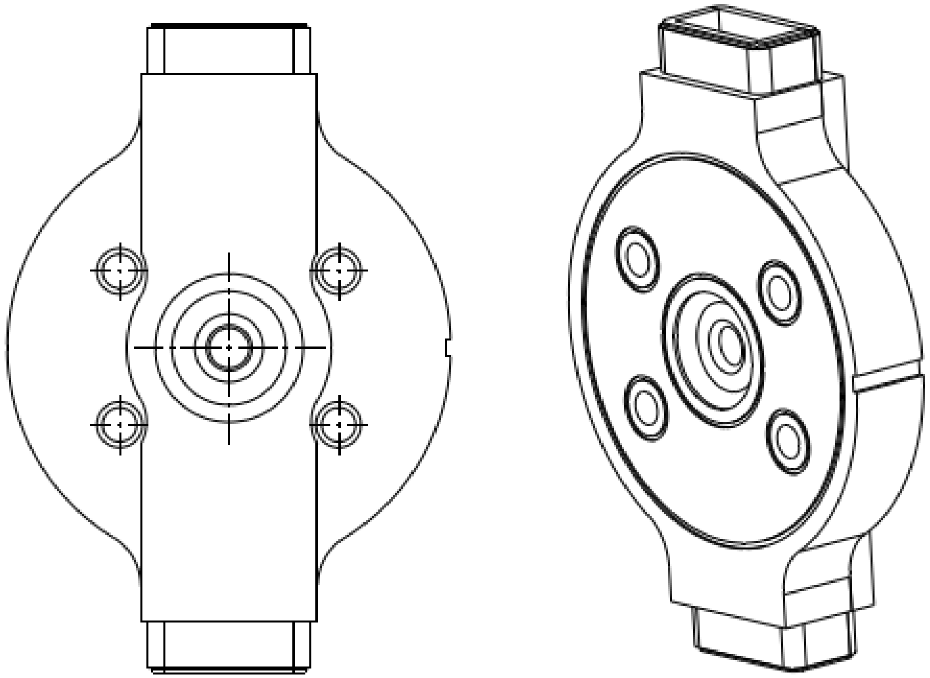
Photon energy

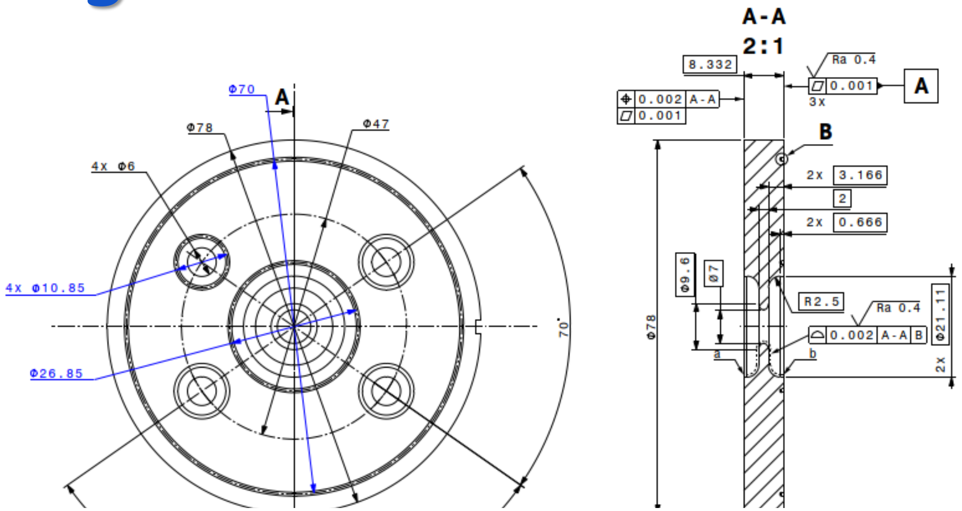
Experimental set-up



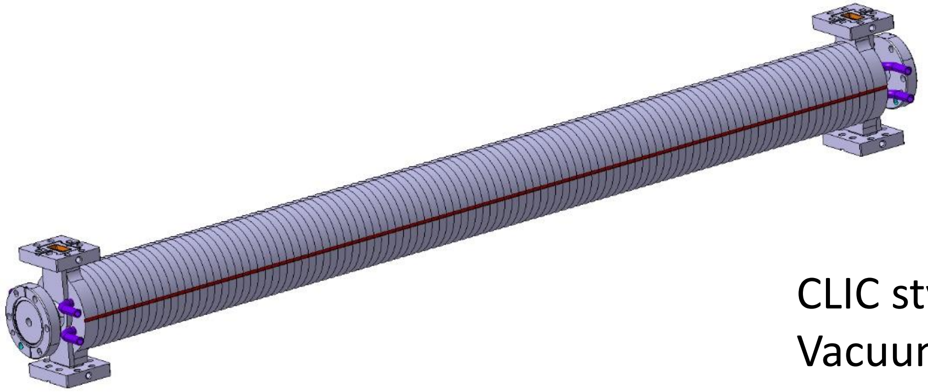


X-band accelerating structure
Mechanical design





Structure to be inserted in a solenoid of 150 mm diameter bore radius



CLIC style tolerances
Vacuum brazing design

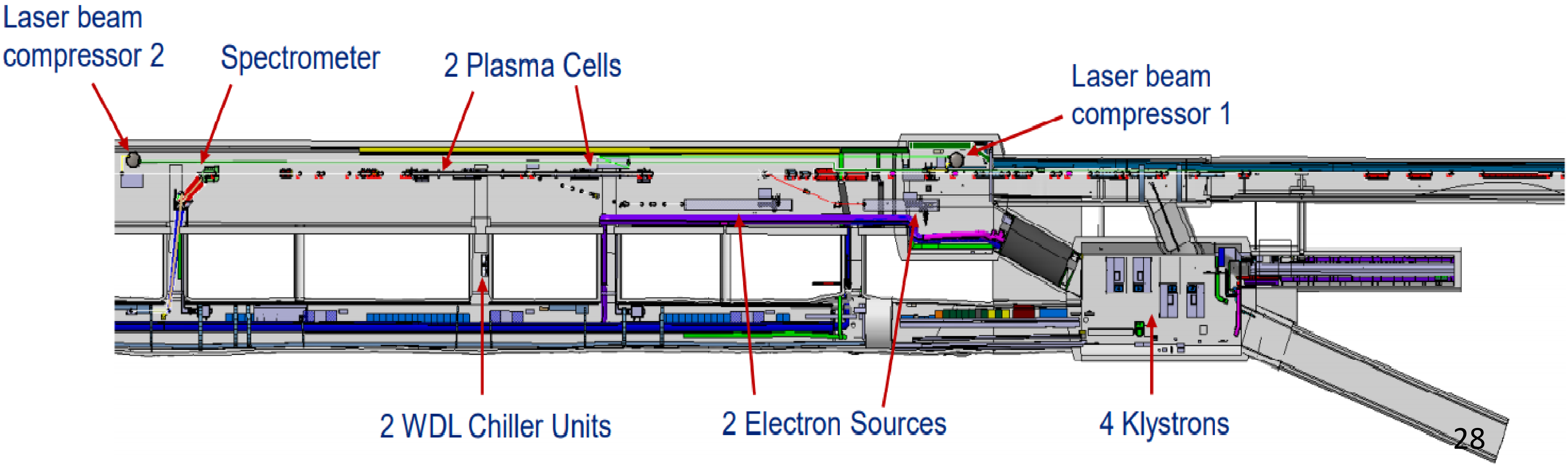
RF-Design made by D. Alesini, M. Diomede, INFN Frascati

Other requirements

- A certain flexibility in the beam parameters which can be delivered keeping good energy spread and emittance
  Energy: +- 10%, Charge +400% ?, Bunch length: 100%, beam size : see transport

- Constraint space for hardware

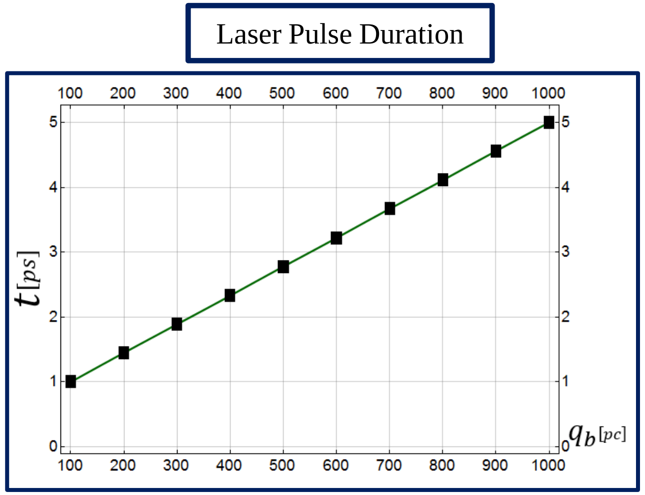
- Excellent timing stability and synchronisation with laser and self modulation device
  30 fs stability

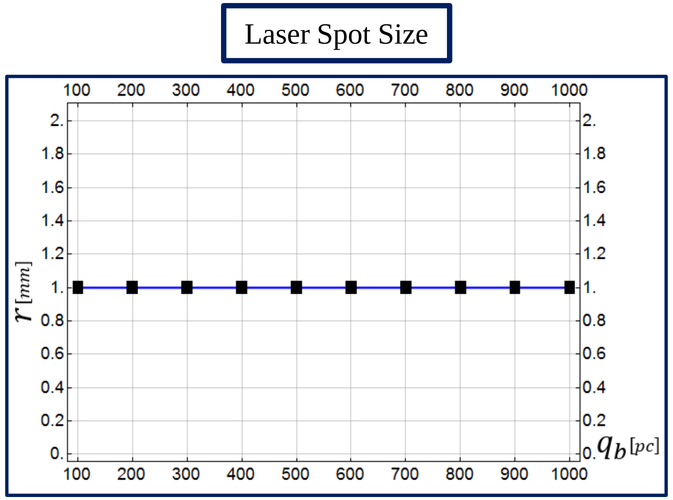


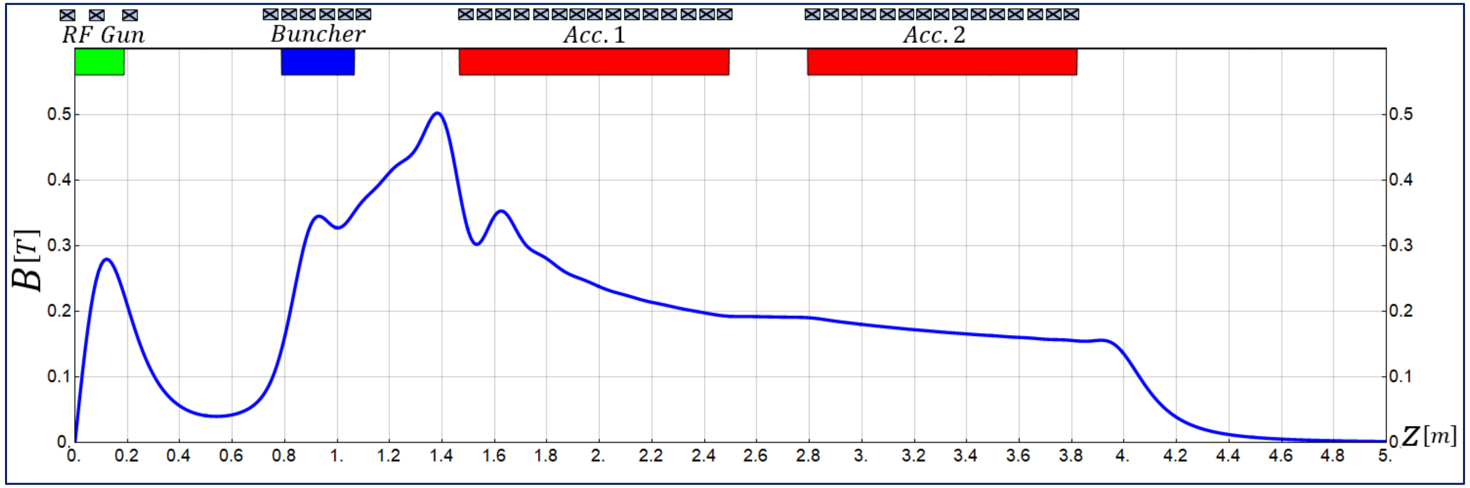
Flexibility to produce higher charge

(for lower plasma density or experimental reasons)

Changing only laser pulse length and adapting magnetic field slightly





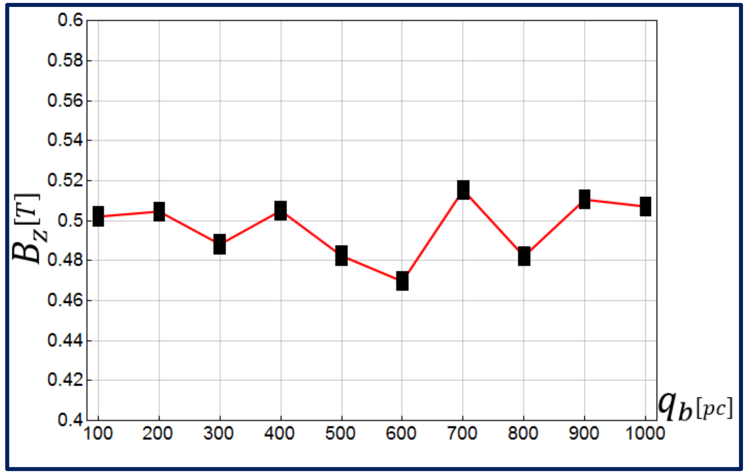


Mohsen Dayyani Kelisani

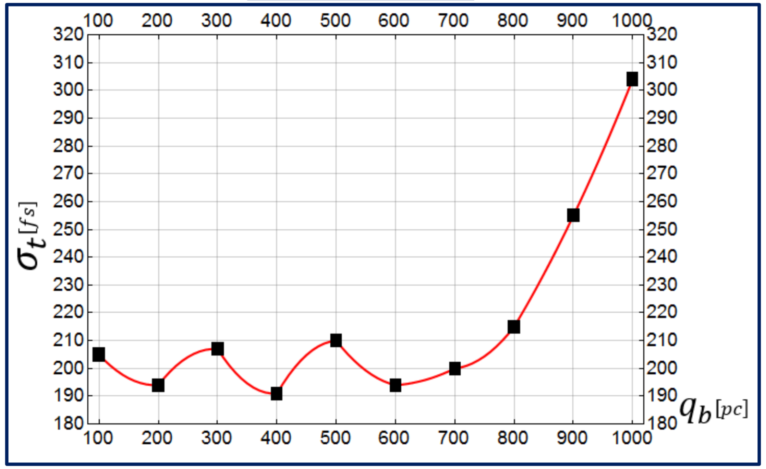
Flexibility to produce higher charge

0.1 to 1 nC per bunch

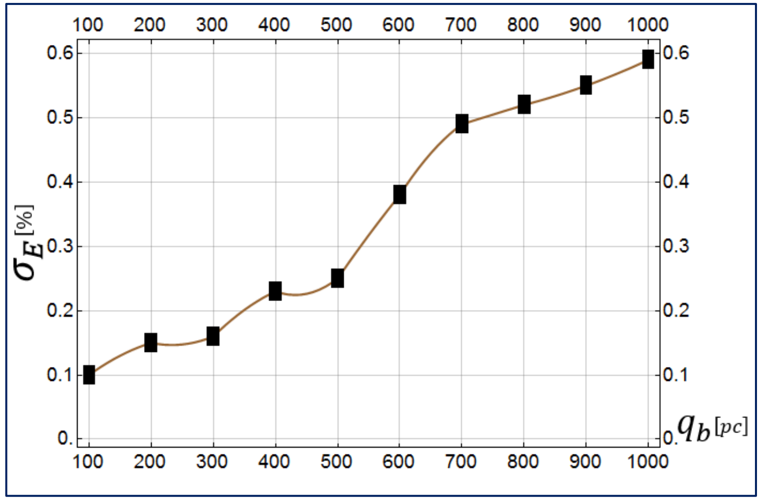
Max_B_z



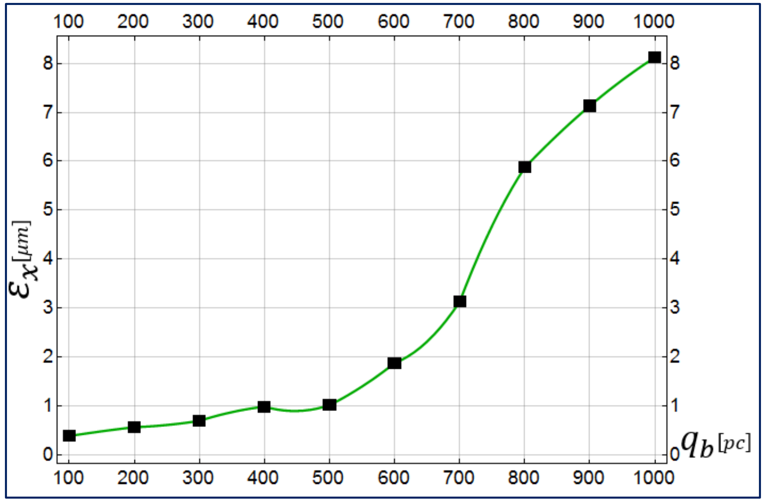
Bunch Length



Energy Spread



Bunch Emittance



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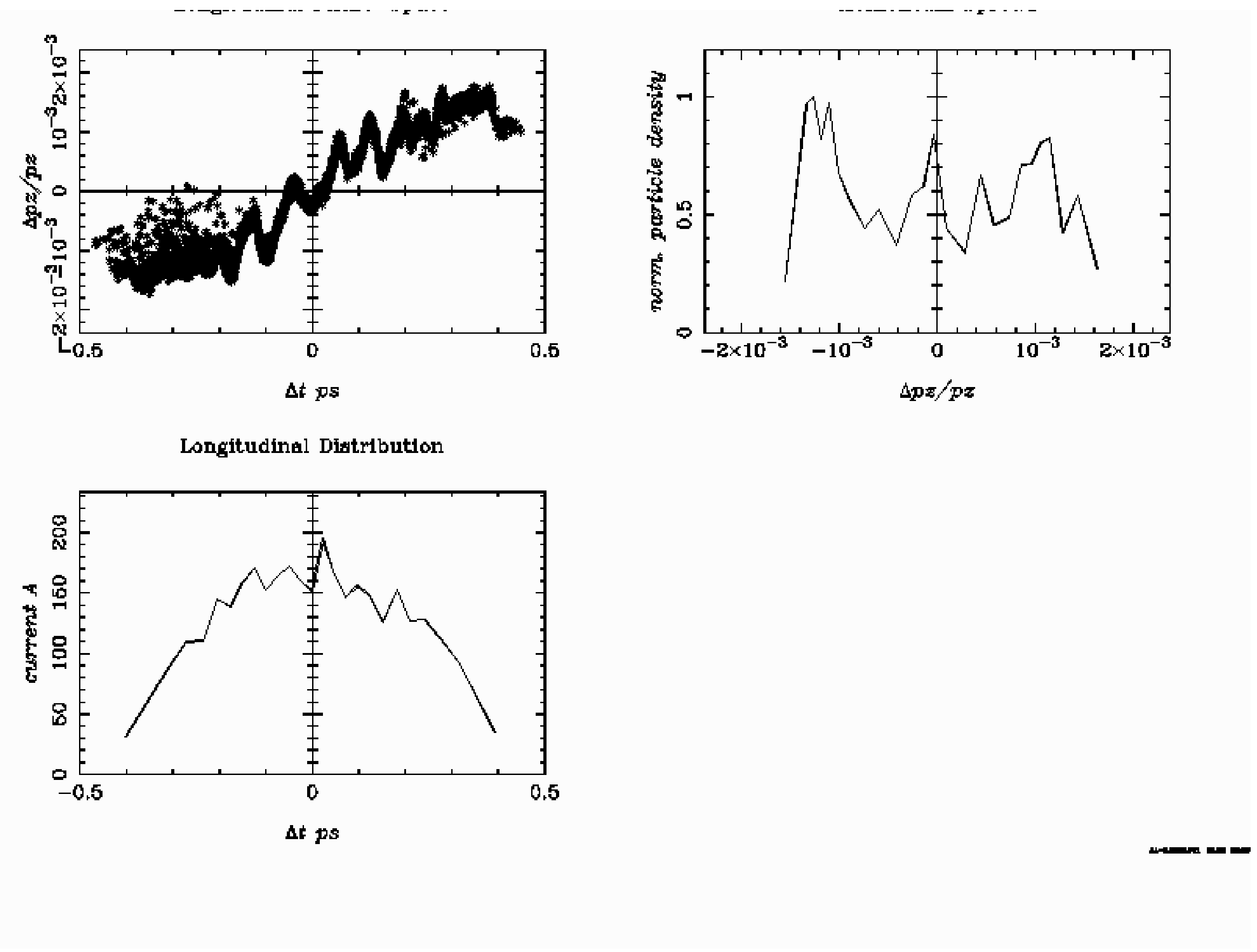
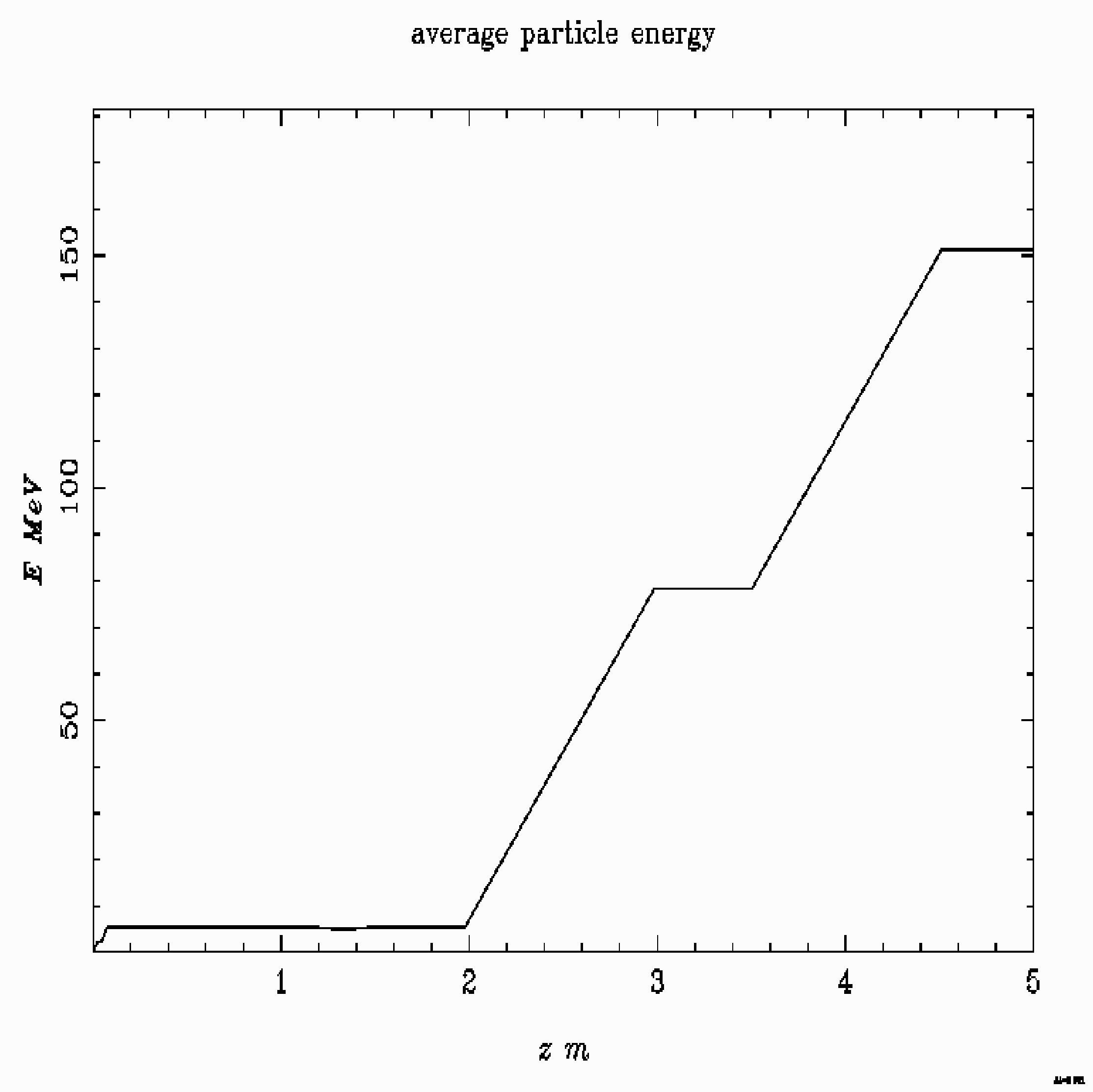
Tentative RUN 2 injector parameter for 150 MeV

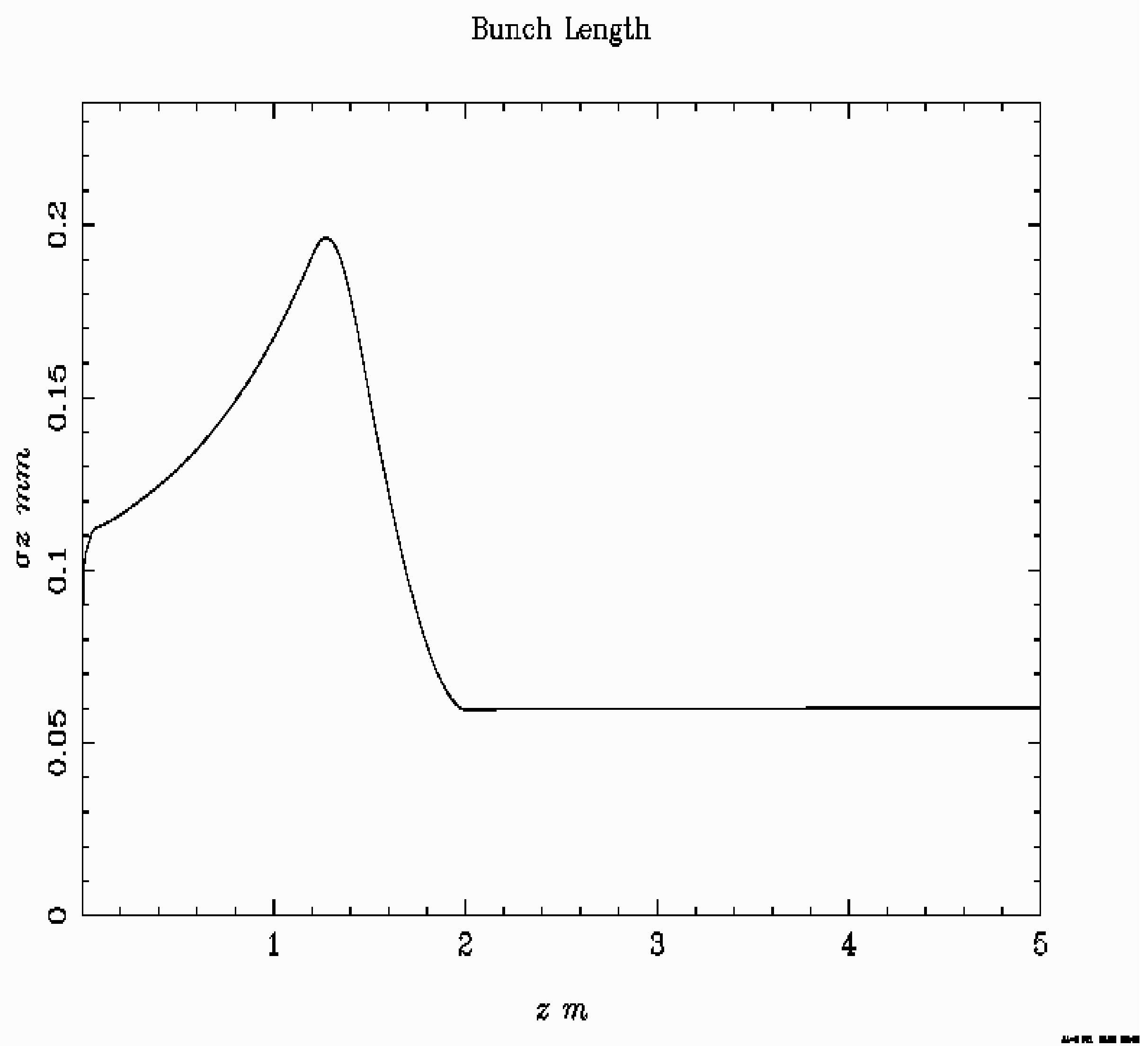
Only scaled down accelerating gradient, identical initial distributions, no new optimization

Energy:	**151.8 MeV**
Energy Spread:	**144.5 keV rms =9.5 10^{-4}**
Emittance: x/y:	**0.7 mm mrad**
Bunch length:	**60 um rms**
Bunch Charge:	**100 pC**

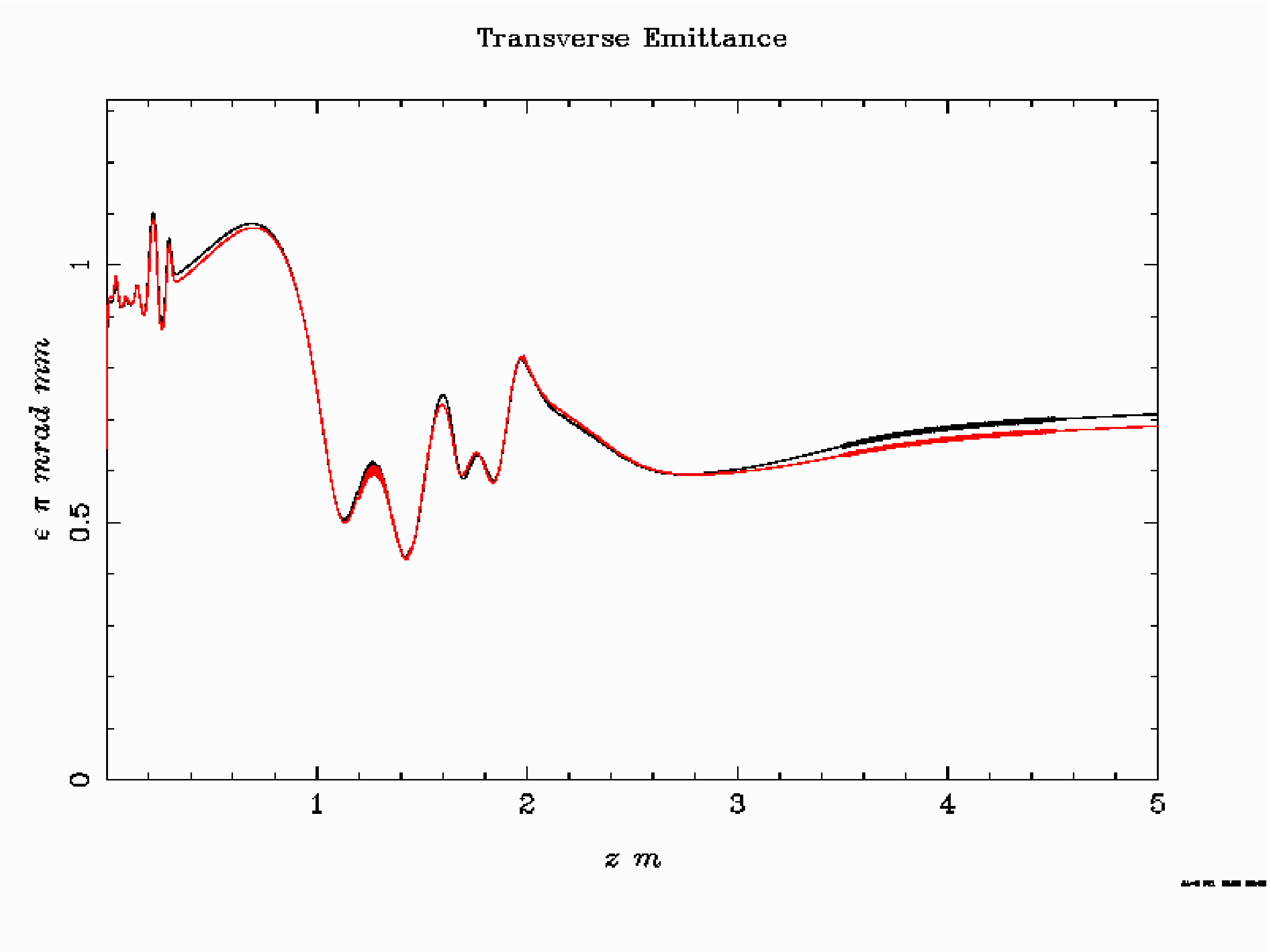


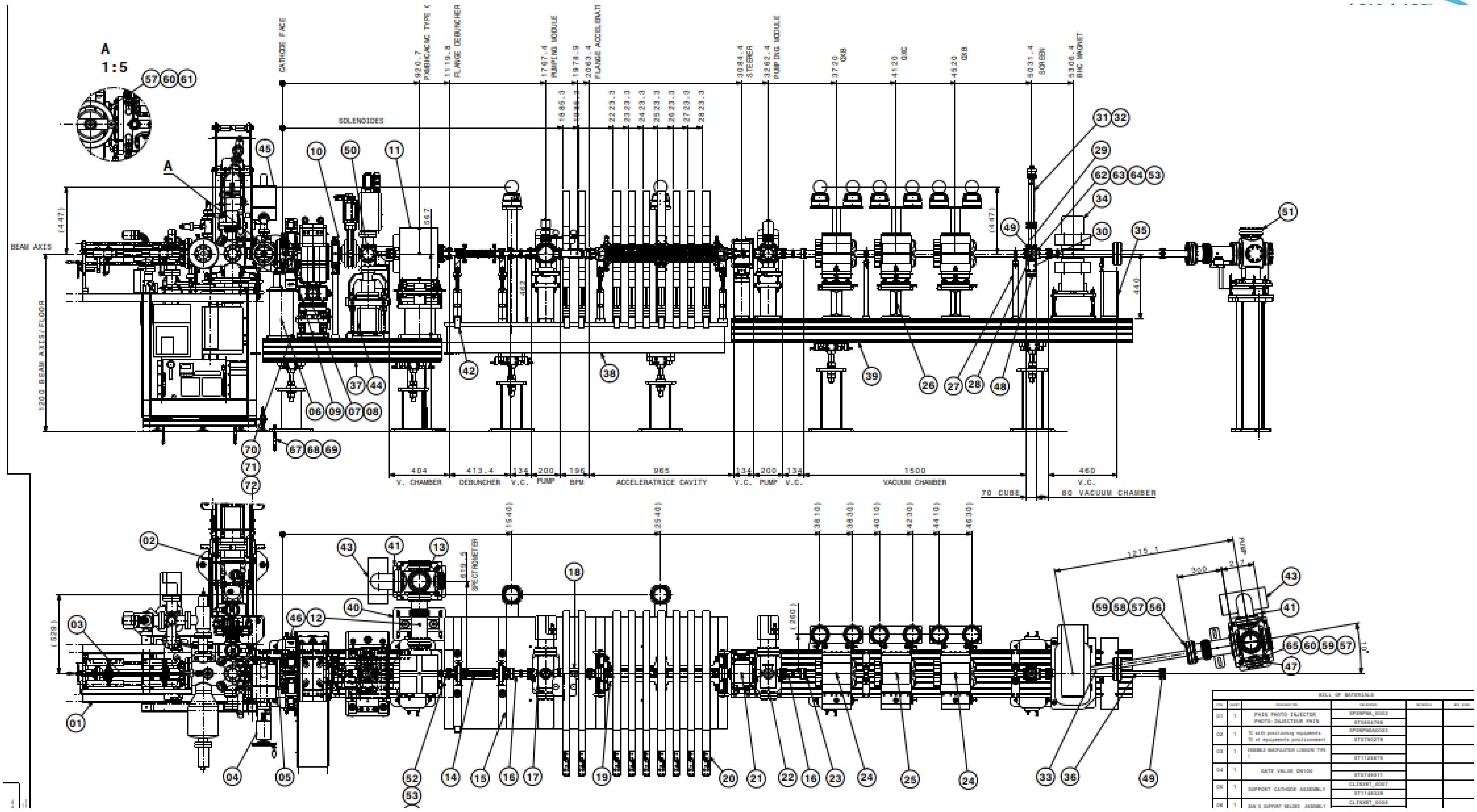
Tentative RUN 2 injector parameter for 150 MeV





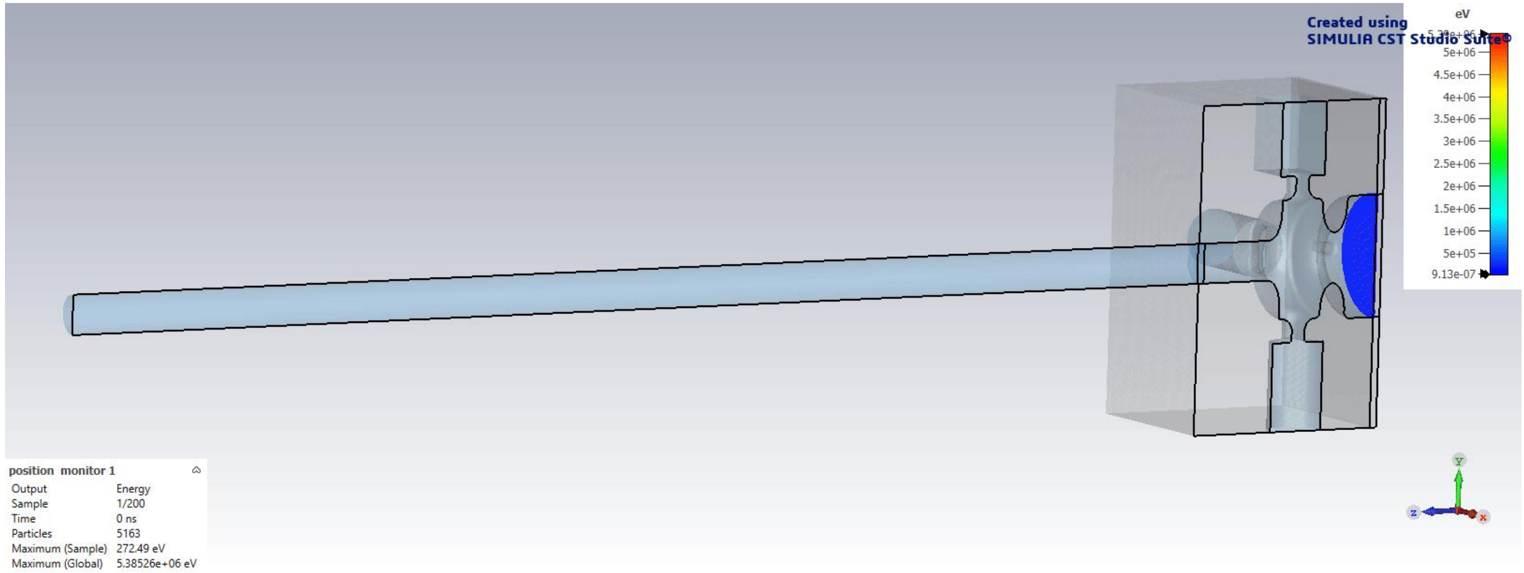
Tentative RUN 2 injector parameter for 150 MeV



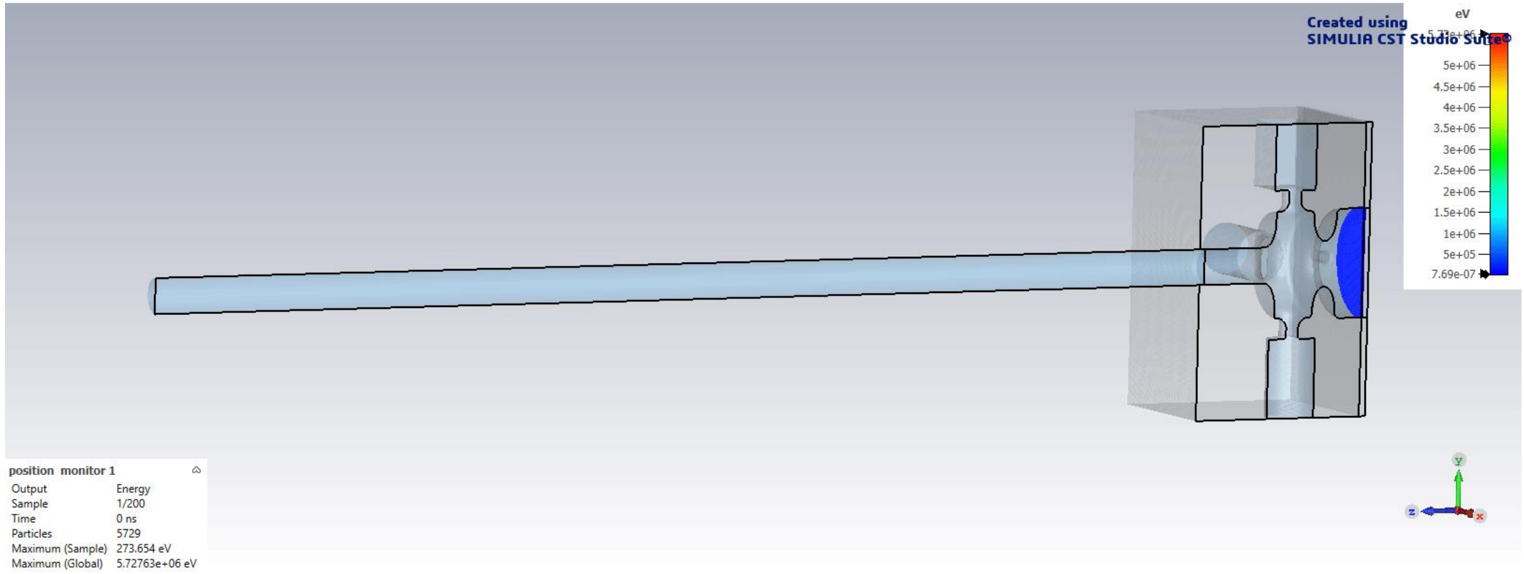

A
1:5
CATHODE FACE
320.7
1119.8
FLANGE DEBUNCHER
1767.4
PUMPING MODULE
1978.9
2083.4
3084.4
STEERER
3262.4
PUMPING MODULE
3720
QXB
4120
QXC
4520
QXB
5031.4
SCREEN
5306.4
BHC MAGNET
SOLENOIDES
1885.3
2223.3
2323.3
2423.3
2523.3
2623.3
2723.3
2823.3
BEAM AXIS
(447)
1200 BEAM AXIS/FLOOR
567
462
440
404
V. CHAMBER
413.4
DEBUNCHER
134
V.C.
200
PUMP
196
BPM
965
ACCELERATRICE CAVITY
134
V.C.
200
PUMP
134
V.C.
1500
VACUUM CHAMBER
460
V.C.
70 CUBE
80 VACUUM CHAMBER
(1540)
(2540)
(3810)
(3830)
(4010)
(4230)
(4410)
(4630)
619.5
SPECTROMETER
(329)
(360)
1215.1
300
PUMP
10°
BILL OF MATERIALS
PHIN PHOTO-INJECTOR
PHOTO-INJECTEUR PHIN
GATE VALVE
SUPPORT CATHODE ASSEMBLY

PIC Dark Current Simulations

No Solenoid

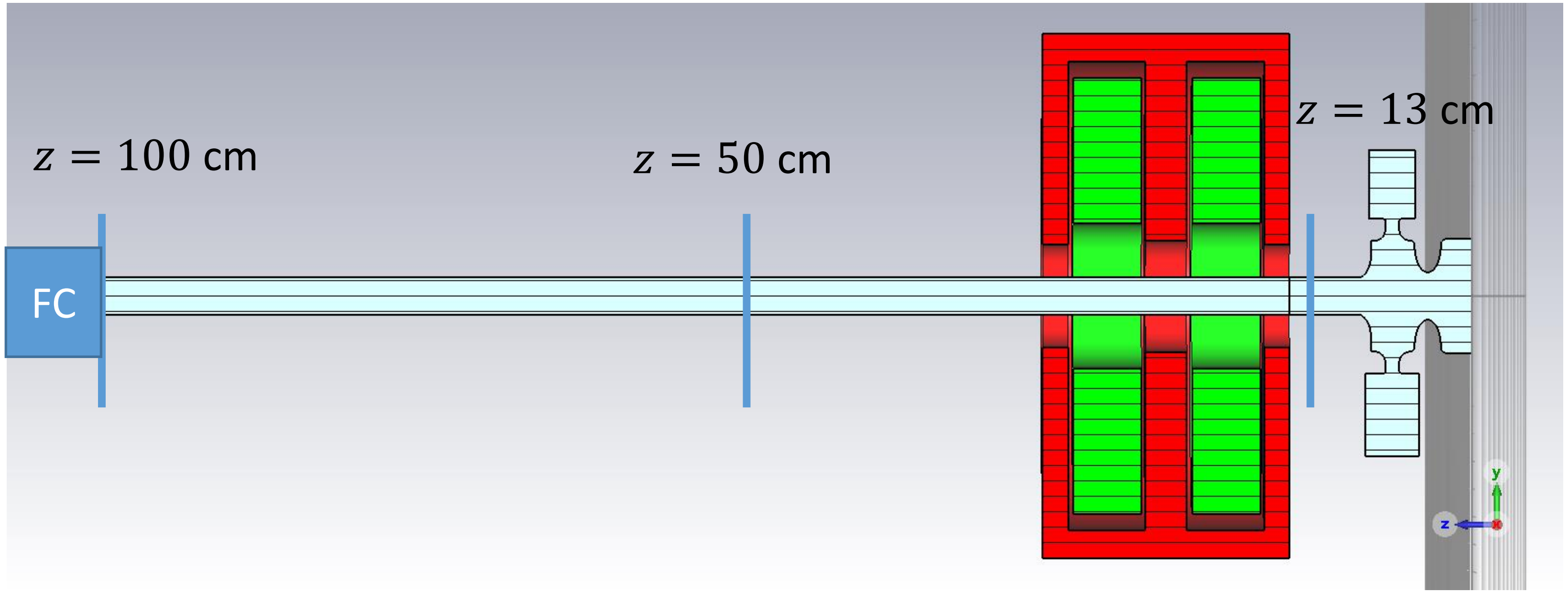


Solenoid: Antisymmetric mode

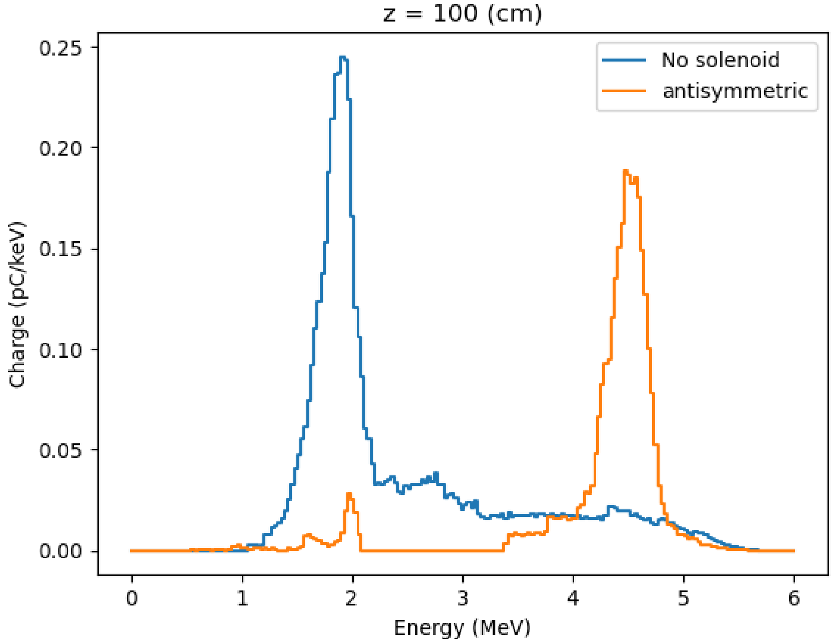


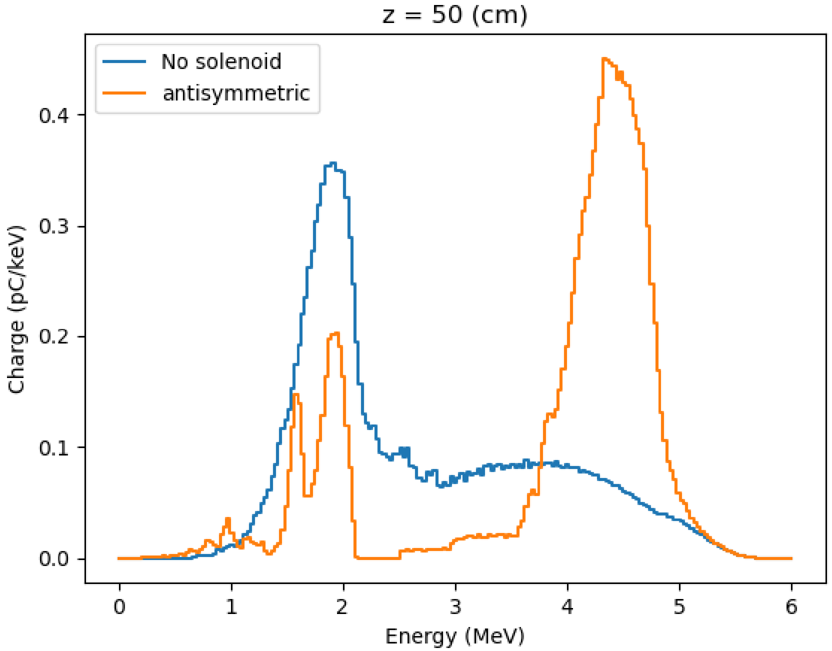
Pablo Martinez-Reviriego, IFIC

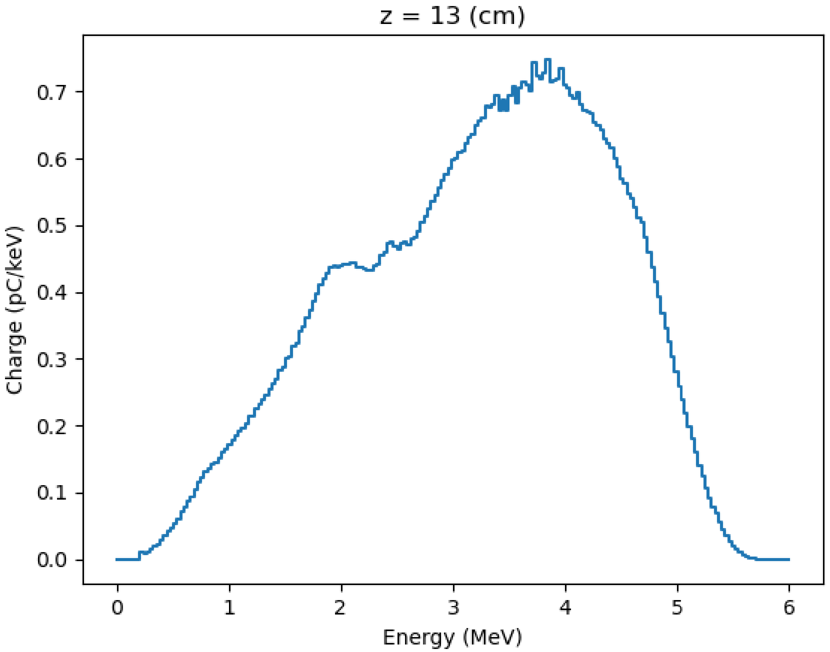
Dark Current Simulations



Pablo Martinez-Reviriego, IFIC

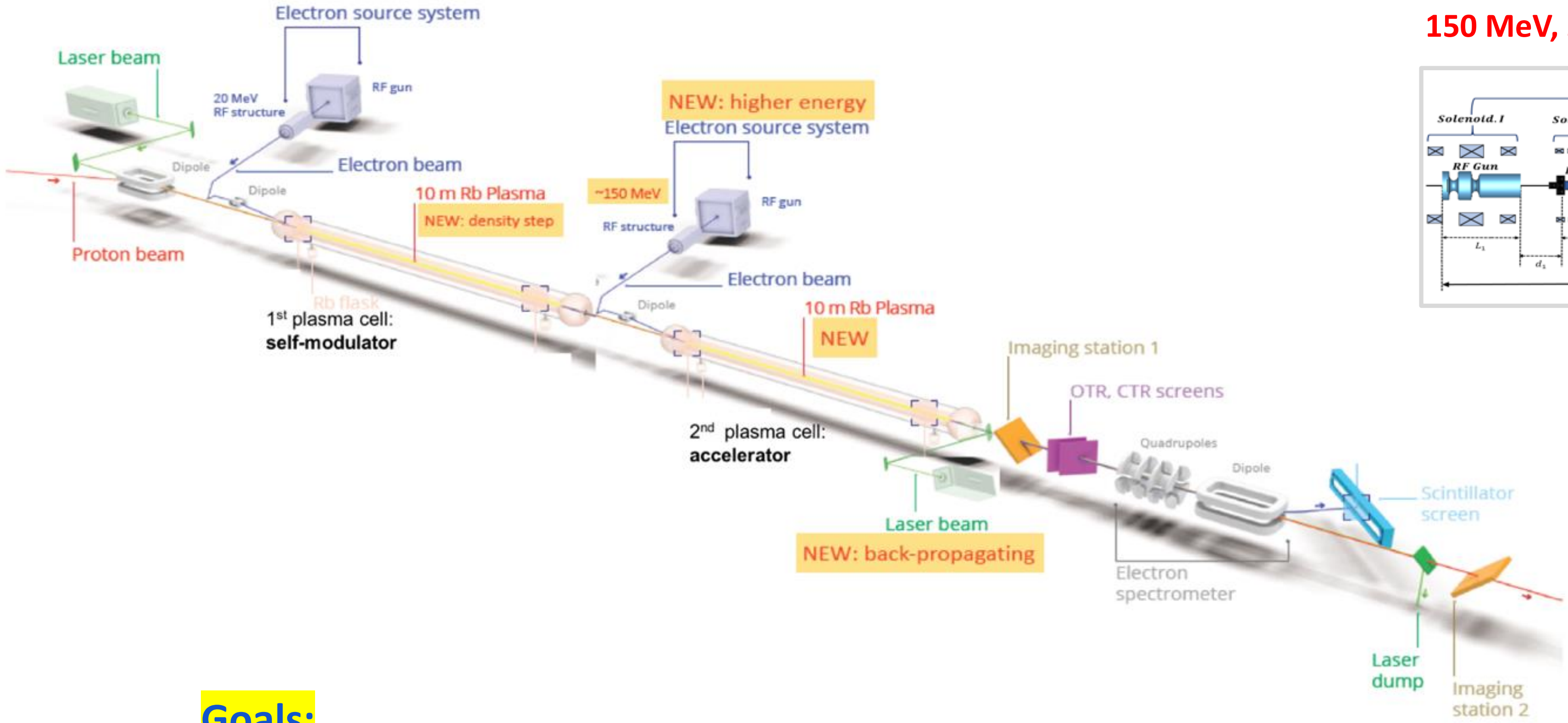




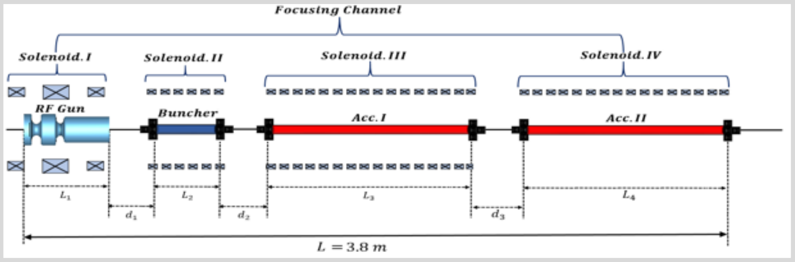


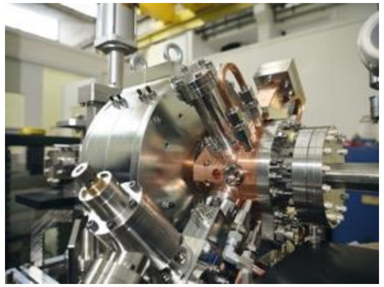
AWAKE Run 2

- ➔ **Demonstrate possibility to use AWAKE scheme for high energy physics applications in mid-term future!**
- ➔ Start 2021! Staged program for ~ 10 years



- → **Need to work in blow-out regime and do beam-loading**
- → **New electron beam based on x-band:**
  150 MeV, 200 fs, 100 pC, σ = 5.75 µm





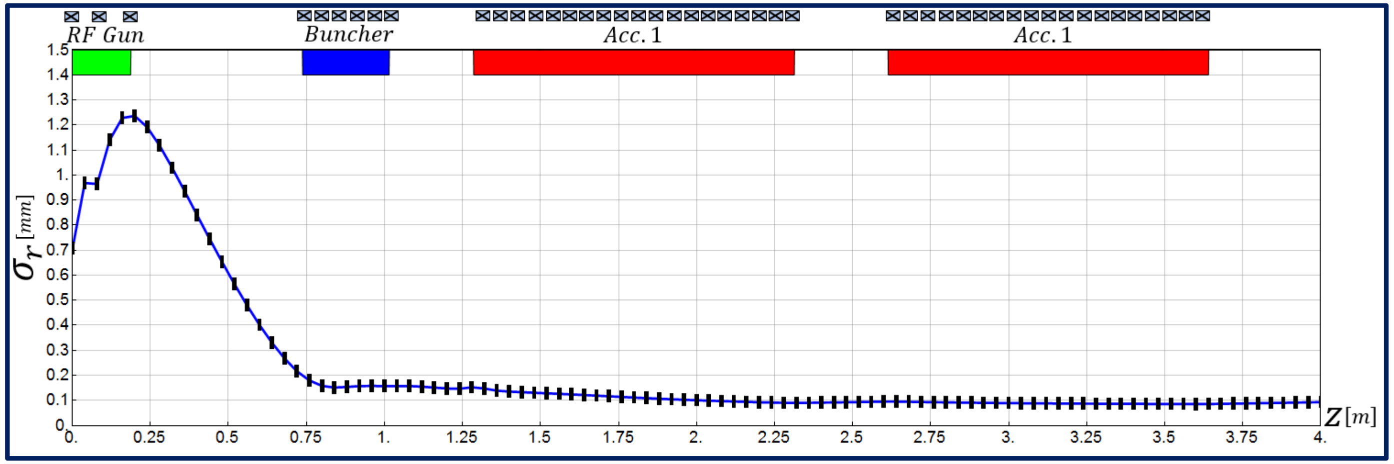
Goals:

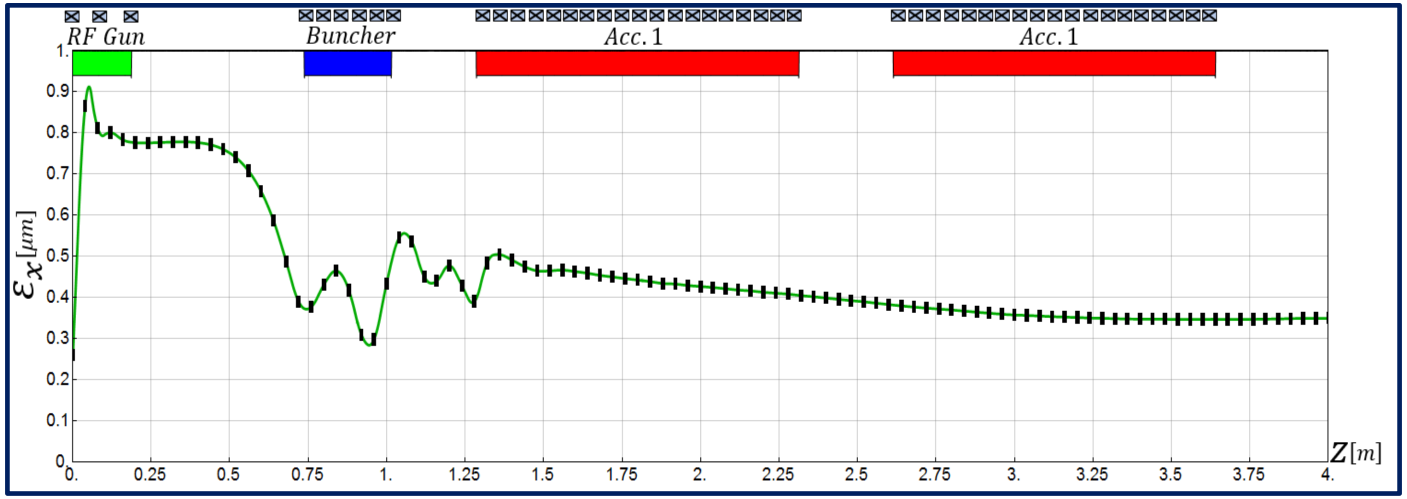
Accelerate an electron beam to high energy (gradient of 0.5-1GV/m)

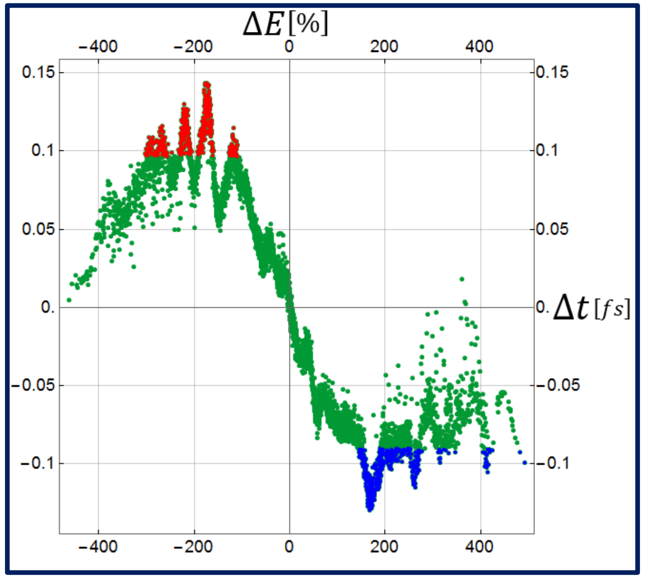
Preserve electron beam quality as well as possible (emittance preservation at 10 mm mrad level)

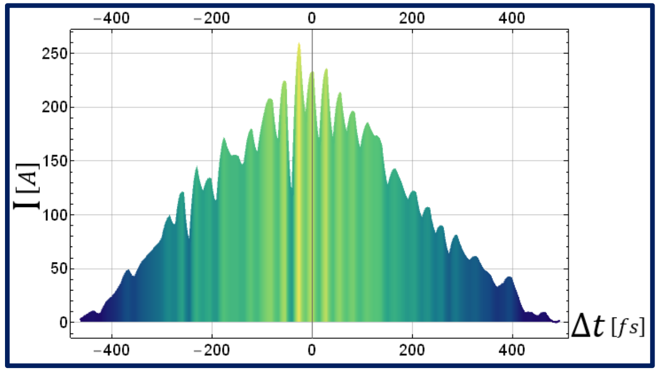
Demonstrate scalable plasma source technology (e.g. helicon prototype)

Reference design









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